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A Study Of Bituminous Coal Washing Methods

A STUDY OF BITUMINOUS COAL WASHING METHODS

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

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SUMMARY

The experimental work reported in this study consisted of the examination of five coals from the Eastern and Central fields to determine their washability, and the examination of a number of washeries in the central field to determine the effectiveness of the methods used.

The coals used in the experimental work were from the Illinois No. 6 seam at Herrin, Illinois, the Bon Air seam at Bon Air, Tennessee, the Indiana No. 3 seam at Terre Haute, Seams "C" and "D" in Clearfield County, Pennsylvania, and the Eagle seam of the Kanawha group in Boone County, West Virginia.

The direct object in the case of the three coals from Tennessee, Pennsylvania and West Virginia was the reduction of the sulfur content to produce a coal suitable for coking or for gas manufacture. The other two coals presented problems in the general reduction of impurities to produce a better coal for the market.

The general scientific object of the study was to determine to what extent coals of the types represented can be cleaned by washing and what are the characteristics of the non-washable coals which cause difficulty.

Three of the samples were submitted because they presented exceptional difficulty to sulfur reduction. The West Virginia coal contained a large proportion, 40.5 per cent, of its sulfur in the organic form; the Bon Air coal, though low in organic sulfur,

contained an exceptionally large part, 37.6 per cent of its sulfur in the form of fine particles of pyrite disseminated through the coal and the Indiana coal was high in both organic sulfur and fine disseminated pyritic sulfur.

The washing tests showed reductions in sulfur content varying from 12 per cent with the Indiana coal to 63 per cent with the Pennsylvania coal. The results led to the following conclusions:

1. The organic sulfur content is not reduced by washing. In some cases there is a larger percentage of organic sulfur in the washed coal than in the original raw coal because of the concentration due to removal of inorganic mineral matter in the refuse.

2. The difficulty in removing the sulfur from the coals which were designated as non-washable is due to the presence of a large percentage of organic sulfur or of fine disseminated pyritic sulfur or, more commonly, of both.

3. The easily desulfurized coal contains a large proportion of its sulfur in the form of pyrite deposits which break free from the coal and form concentratable high specific gravity particles.

4. The sulfur and ash do not always occur together in coal. A large amount of heavy mineral matter may be taken out and still leave the washed coal high in sulfur.

5. Difficulty in removing the ash from a coal by washing is due either to a large percentage of middling consisting of boney coal, carbonaceous shale or mixed particles of shale and coal or to a large proportion of fine inherent ash distributed through all the coal.

6. In washing a raw coal containing fine material the dust is not cleaned. If the coal contains a large amount of clay this goes into the sludge or fine washed coal so that it may be higher in ash after washing than before.

7. In treating a natural feed of a wide range of sizes including the dust on the concentrating table the loss of good coal in the refuse consists almost entirely of large particles and the refuse in the washed coal consists of small particles, mainly dust, through 100 mesh in size.

8. In all the table washing tests the coarser material heavier than 1.80 in specific gravity, was almost all

removed leaving from 0.4 to 0.5 per cent in the washed coal. This percentage appeared to be about the same for all the tests regardless of the proportion of this material in the feed. These results were secured on coals ranging from 7.5 to 30.0 per cent in ash. As complete a removal of the heavy fraction of a very high ash material such as a picking belt refuse or an Alaskan coal would not be expected.

9. The washed coal generally contained a smaller percentage than the raw coal of middling particles above 1.45 specific gravity, but as a rule the proportion of middling particles of 1.35 to 1.45 was no lower in the washed coal than in the raw coal. This refers to table washing tests in which an attempt was made to secure the cleanest product possible even with considerable sacrifice in yield of washed coal if necessary.

10. In the tests, the concentrating table was found to be a little more effective than the jig in reducing the ash and sulfur content of the coal. This is largely due to the fact that, at the fine size to which coal is crushed for table treatment, the dirt particles are more completely detached from the coal particles than in the larger sizes at which coal is jigged. It is probable also that the table makes a closer specific gravity separation than the jig.

11. In preparing coal for coking, where fine size is not objectionable, the table may be used to advantage. In preparing coal for fuel, the greater reduction in ash and sulfur is more than offset by the disadvantage of fine size.

ACKNOWLEDGEMENT

Mr. H. F. Yancey, Assistant Chemist, U. S. Bureau of Mines, did the analytical work connected with this study and worked with the writer on the experiments conducted in the field and in the laboratory. Professor H. H. Stoek of the Department of Mining Engineering of the University of Illinois, contributed valuable suggestions in the prosecution of the experimental work and the arrangement of the manuscript. Mr. E. A. Holbrook, Assistant Director, and Mr. George S. Rice, Chief Mining Engineer of the U. S. Bureau of Mines, made many helpful suggestions. To all these grateful acknowledgement is made.

A STUDY OF BITUMINOUS COAL WASHING METHODS

CHAPTER I

INTRODUCTION

1. The Objects of Coal Washing. The practice of washing coal to separate it from the inert mineral matter which is found associated with it when mined, constitutes an industry which is receiving more and more attention as the necessity for utilizing the deposits of lower grade coal becomes more apparent.

Briefly stated the objects accomplished by coal washing are the concentration of the combustible matter by the removal of particles of heavy ash-forming minerals such as shale and slate; and the removal of a part of the sulfur and phosphorus which are detrimental in the use of the coal for metallurgical coke.

These objects are accomplished by taking advantage of the fact that when particles of varying densities are agitated together in water they stratify arranging themselves according to their respective specific gravities with the heaviest particles at the bottom and the lightest at the top. Shale and slate being higher in specific gravity than coal may be separated from it in this manner. The equipment used consists largely of machines and appliances developed in the ore mining industry for the separation of ores from the barren rock mined with them. Ore concentration and coal washing depend upon the same principles and are similar

operations with the exception that whereas in ore dressing the valuable concentrate usually constitutes the heaviest and least bulky product, in coal washing it is the lighter and bulkier material which is saved and the heavy concentrate is the refuse discarded.

The development of the coal washing industry in America has been very largely in the hands of the iron and steel manufacturing companies, who have acquired coal lands and mined and washed the coal in order to assure themselves of a supply of low sulfur coal suitable for the manufacture of metallurgical coke. Some of the coal mining companies, which produce coal for the market, have followed this lead and installed washeries in order to produce a more marketable coal.

2. Advantages of Producing Clean Coal. The sole purpose of the coal mine operator being to make a profit by his operations, and the amount of this profit depending as it does very largely upon his output and the price which he receives for his coal, it is obvious that any method of preparation which will give him a decided advantage in a competitive market or which will enable him to sell his product at a premium should be of great value. By operating a washery both of these advantages may be acquired. A cleaner, better looking, more salable coal will be produced, which may make possible the operation of the mine when others in the same field may be idle for lack of orders.

Small unwashed coal, the market for which is practically limited to the operators of large power plants equipped with chain grate stokers, becomes, after washing, readily salable as domestic, coking or steam coal. At one mine in the Williamson County field where a washery is operated, practically all the production of three

inch screenings with the exception of the No. 5 washed coal, 0"-$\frac{1}{4}$" size, is sold for other purposes than steam raising. The number 1 nut (2"-3") is sold as domestic coal, the larger part of it being used for heating Chicago apartment houses. The No. 2[1], 3 and 4 sizes are used for by-product coking, cement burning and for domestic coal.

In some cases the use of a coal washer makes possible the profitable operation of a mine in coal which without some method of cleaning could not be marketed. This is the case in some of the isolated districts in the west where the high transportation charge on outside coal gives the local operator a sufficient margin to cover the cost of a quite elaborate system of preparation. The coals of Montana and Washington are largely of the type which must be treated by some cleaning process before they can be used. The Alaskan coals also occur interbedded with shale and slate in such a manner that the coal as a rule cannot be mined clean enough to use in the raw state.

While as a rule contracts covering the sale of coal on specification provide for the payment of a premium, often two cents per ton, for each unit of reduction in the percentages of ash below the amount specified as allowable, this premium is generally not sufficient to make washing profitable. At present the possibility of securing a higher price for coal after washing depends very largely upon finding a market for it in those industries, such as steel manufacture, by-product coking, gas making and the ceramic

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[1]In Illinois the following sizes for washed coal have been generally adopted as standard: No. 1, 2"-3"; No. 2, 1"-2"; No. 3, $\frac{3}{4}$"-1"; No. 4, $\frac{1}{4}$"-$\frac{3}{4}$"; No. 5, 0"-$\frac{1}{4}$".

industries which require a low sulfur and low ash coal.

That these industries will, in the future, have to draw part of their supply from fields outside the present restricted areas of production of low sulfur coal in West Virginia, Kentucky and Pennsylvania is becoming obvious. While our reserves of coal, which like that from the Connelsville district, can be made into good metallurgical coke without washing are by no means nearing exhaustion, the big consumers of low sulfur coal cannot provide for their future needs by extending their holdings of coal land in these fields. Furthermore, their rate of production has about reached the peak, and cannot be expected to keep pace with the increased consumption of low sulfur coal in the metallurgical industries. The deficiency will have to be made up by the use of washed coal from other districts where inferior coal is produced.

The rapid growth of the by-product[1] coking industry, as distinct from the iron and steel business, for the production of coal gas and fuel coke for the market furnishes an entirely new market for washed coal from the desirable ~~coals~~ seams of poorer quality. For this purpose a coal is not generally subject to as strict requirements with regard to sulfur and ash content as a coal to be used for metallurgical coke. The limit for sulfur is commonly placed at one and one-half to two per cent.

That the production and use of cleaner coal for all purposes would result in a great saving to the industries of the nation goes without saying, but the coal mine operator cannot be ex-

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[1]In 1920, for the first time, the production of by-product coke in the United States exceeded the production of bee-hive coke.

pected to supply washed coal to the market unless it commands a sufficiently higher price to pay the additional cost of the washing operation. A demand from the users of coal for a cleaner product and a willingness to pay for the increased value received will make possible the washing of coal for fuel.

The two chief advantages to the operator of producing washed coal are a wider and more dependable market for his coal and a higher selling price. These two advantages are being accentuated as the users of coal realize more fully the advantages of using clean coal and the great losses due to handling the worthless dirt in raw coal thru the cycle of production, transportation and utilization.

3. Advantages of Using Clean Coal. The importance of this subject of clean coal will vary more or less with the widely different uses to which it is put. In certain manufacturing processes where the coal or some of the products derived from it enter into the composition of materials, which would be damaged by the addition of sulfur or phosphorus, the use of clean coal is mandatory. The principal industries which require low sulfur coal are iron and steel manufacture, gas manufacture, the ceramic industries, the smelting of ores and the heat treatment of metals.

On the other hand, to the great majority of consumers who use coal for fuel, the advantage of the use of washed coal is simply a matter of dollars and cents. It is impossible to discuss fully the application of the problem of dirt in all the varied uses to which coal is put, but two typical cases representative of the two classes outlined above will show in a general way the extent of the economic losses which are directly chargeable to excessive im-

purities in coal.

WASHED COAL FOR COKING

For the manufacture of metallurgical coke, particularly if it is used in iron and steel making, a low sulfur coal producing a coke of about 1.10 per cent sulfur or less is required.

Some of the Eastern coking coals, such as the Connelsville and the Elkhorn, come well below this limit in the raw state, but with many other coals which posses good coking qualities washing is necessary in order to reduce the sulfur content to this figure. In the southern and western fields most of the coal used for coking, though low enough in sulfur, must be washed because of excessive ash.

In regard to the use of washed coal for coking Wagner[1] says, "It is an unquestionable fact that coal washing will greatly assist in producing a high grade coke, as even a comparatively low ash coal will occasionally run high in ash and possibly sulfur, due to careless mining or to the irregularity of the coal seam, the washing insuring a more uniform quality of coke". An example from actual practice will best show the relative advantages of washed coal and raw coal for making metallurgical coke. The following figures are taken from a report[2] on results secured at the plant of the Nova Scotia Steel Company.

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[1]Coal and coke p. 104.

[2]W. H. Graham Trans. Canadian Min. Inst. 1918 - 231.

TABLE I

Coke From Raw and Washed Coals, Nova Scotia Steel Company

	Raw slack	Coke from raw slack	Washed slack	Coke from washed slack
Coke yield per cent		64.5		62.0
Volatile per cent	35.0		38.0	
Fixed carbon per cent	53.0	81.5	58.0	93.0
Ash per cent	12.0	18.5	4.0	6.6
Sulfur per cent	2.0		1.2	

Since the heating value of coke varies with the carbon content, this shows an increase of 14 per cent in calorific value of coke from washed coal as compared with coke made from the unwashed coal. The washed coal also contains 8.5 per cent more volatile than the raw coal and will therefore produce an 8.5 per cent larger volume of gas, neglecting the amount of gas occluded in the coke. The washed coal de-ashed to the extent shown above produced 4 per cent less coke. These advantages lead to a further advantage in increased oven capacity, in weight of actual coal coked, volume of gas produced, and effective carbon in the coke produced.

The decreased capacity of equipment and the increased cost of handling throughout the cycle of operations due to the use of coal containing an excessive amount of worthless ash forming minerals is apparent to all, and the losses accruing in actual operation are usually greater than the theoretical calculations indicate.

In the blast furnace a ton of coke from washed coal gives 230 pounds more available carbon and 24 pounds less ash to be slagged than a tone of coke from unwashed coal. Thus a smaller amount of fuel is needed to maintain the required temperature and a smaller amount of lime is needed to slag off the impurities in the

coal. For this reason a much larger amount of ore can be charged.

Perhaps the greatest value of the washing process as applied to coking coals lies in the production of a coke of more uniform ash and sulfur content. It is possible to produce good pig iron from high sulfur coke if the right conditions can be maintained in the furnace, but temperature control, always a difficult thing in blast furnace operation, is impossible with coke of irregular composition.

For instance if the charge is calculated on the basis of 1.20 per cent sulfur and 5.00 per cent ash in the coke and a batch of coke containing 1.60 per cent sulfur and 10.0 per cent ash goes in, as soon as this coke of lower calorific value reaches the reduction zone of the furnace, the chemical reactions are arrested, the silicon goes down, slagging of the sulfur is arrested and a cold furnace producing high sulfur white iron is the result.

On the other hand if the charge is figured for coke of 1.6 per cent sulfur and 10 per cent ash with the right proportion of lime to flux and absorb these impurities, and a charge of good coke goes in, the furnace gets too hot, the chemical reactions are intensified and an iron too high in silicon for the basic process is produced. These difficulities cause a great reduction in capacity of the furnaces and a bad slag as well as impure iron. Graham in discussing the effect of high ash in the coke says, "In a furnace producing No. 1 basic iron, the loss of iron in the slag increases from 1.0 per cent to 8 or 10 per cent in a cold furnace".

WASHED COAL FOR FUEL

Primarily, of course, the increase in fuel value of a coal due to washing consists in the increased proportion of valuable

combustible material due to the removal of excess ash. Mr. Thomas J. Drakeley[1] in a recent extensive investigation of the relation of ash content and the calorific value of coal, confirms the conclusions of earlier authorities that for a given coal the decrease in B. t. u. content with increase in ash content is practically uniform and constant. In the average coal where the dirt is chiefly shale and slate, the calorific value decreases about 1.2 per cent for each per cent of increase in ash content. If this were the only disadvantage of using dirty coal the consumer would have small grounds for demanding washed coal, as the difference in price of coals of different quality is ordinarily more than sufficient to compensate for this decreased B. t. u. content due to high ash. However, this constitutes only a small proportion of the total loss chargeable to excessive dirt in coal. The various factors which make up the total cost of using dirty coal may be classified under three headings as follows:

1. Cost of handling worthless material.
2. Effect of high ash content on thermal efficiency.
3. Decrease in capacity of plant equipment.

Since more than half of the bituminous coal used for fuel in this country is burned under boilers for the generation of steam, an analysis of these three items of waste in the use of dirty coal for steam raising will best represent the case. Losses in other uses of coal are similar but perhaps different in degree.

COST OF HANDLING WORTHLESS MATERIAL

The first loss incurred in the use of dirty coal is the

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[1]Calorific Value and Ash Yield of Coal Samples From the Same Seam T. I. M. E. Oct. 1918.

freight charge for the transportation of worthless material from the mine to the point where consumed. This is a loss which accrues to every user of coal for any purpose unless his plant is located at the mine. Where the transportation charge amounts to as much as $1.50 per ton, which is about the present rate from the Danville district to Chicago, the cost of hauling the worthless material in a coal containing 6 per cent of removable ash amounts to enough to cover the expense of cleaning in an efficiently operated washery.[1]

Generally speaking, the Central District coals of washable size, under three inches, contain at least 6 per cent of free dirt as marketed in the raw state. This applies to the average two inch screenings ordinarily used for steam raising and probably a large part of the domestic coal of stove or nut size. Holbrook[2] gives the average ash of 32 samples of Illinois screenings collected from various parts of the state as 17.4 per cent with a minimum of 10.1 per cent and a maximum of 29.7 per cent. Assuming the fixed or irremovable ash at 10 per cent, this indicates an average free ash content of 7.4 per cent. Under the extra cost of handling may be included in addition to the increase in freight charges, the increased labor or power required for handling coal after it reaches the plant, increased storage space required if coal is stored, and cost of increased ash disposal.

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[1]An arbitrary deduction for the moisture in washed coal is commonly made by the Mining Co. in billing out the coal and by the Railway Company in computing freight bills this amounts to from 3 to 15 per cent of the mine weight.

[2]Dry Preparation of Bituminous Coal at Illinois Mines, Eng. Exp. Sta. Bull. 88.

EFFECT OF HIGH ASH CONTENT ON THERMAL EFFICIENCY

As already pointed out the B. t. u. content of a fuel decreases about 1.2 per cent for each per cent of increase in ash content, but the decrease in effective heat units actually liberated when the coal is burned on the grates is much greater than this. The percentage of ash has a distinct influence on the thermal efficiency of the furnace. As the percentage of refuse in the fuel increases, it becomes more difficult to secure complete combustion of the good coal. With a reasonably clean coal and good firing, we expect the ash as removed from the grate to contain approximately 25 per cent of its weight of unconsumed combustible. As the ash content of the coal fired increases, the percentage of combustible lost in the ash also increases very rapidly.

This reduction in effective heating value for increasing percentages of ash is shown graphically in Fig. 1 reproduced from a publication of the J. G. White Engineering Corporation.[1] The first column at the left represents the heating value of ash free coal of 15,000 B. t. u. content, the other columns represent the relative values of coals containing varying percentages of ash. The upper section of each column represents the loss due to the fact that the ash replaces its weights of combustible, the second section represents the loss due to unburned combustible matter lost in the boiler ash, the third section represents the normal loss due to the fact that steam boilers cannot be operated at 100 per cent efficiency. The lowest, <u>black</u> section, therefore, shows the relative commercial values of coal containing these varying percentages

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[1]Clean Coal, The Effect of High Ash Upon the Thermal Efficiency, Amount of Boiler Plant, Amount of Transportation Equipment.

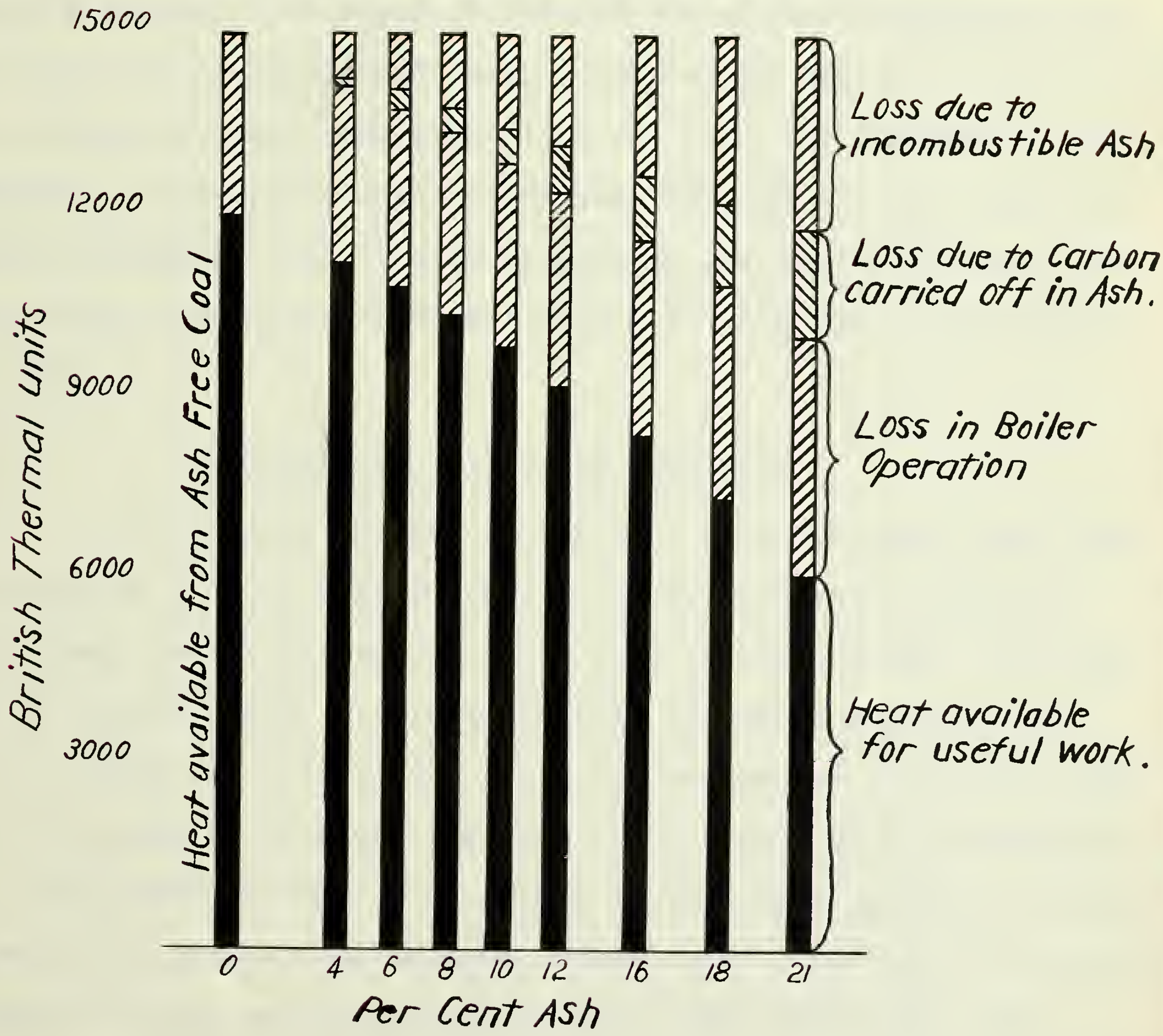

Fig. 1. Reduction in Heat values due to presence of Ash in coal.

of ash.

This reduction in boiler efficiency greatly increases the amount of coal that must be purchased to produce a given amount of power. Using the best coal containing 4.0 per cent ash, approximately 3 pounds is required to produce one boiler horsepower hour, and with coal of 10 per cent ash, less than 3½ pounds is required. When the ash content goes above 10.0 per cent the increase in consumption is very rapid until at 21 per cent ash the coal used per boiler horsepower hour is 5.45 pounds, 80 per cent more than with 4.0 per cent ash coal and 60 per cent more than with 10 per cent ash coal.

DECREASE IN CAPACITY OF EQUIPMENT

The greatly increased amount of high ash coal which must be burned to produce a given power output, when using inferior coal, leads inevitably to a further loss by cutting down the capacity of boiler plant. It is impossible to burn a sufficient amount of high ash coal on the grate to produce the same power output as is secured in operating with clean coal. This is possibly the effect which is felt most keenly by the plant operator, because in order to produce a given power output with dirty coal he requires a larger capital outlay for boiler plant than with clean coal.

The publication of the J. G. White Engineering Corporation referred to above gives the following data on this phase of the subject:- With coal containing 6 per cent ash eight 500 h.p. boilers can be made to generate 300,000 pounds of steam, equivalent to a peak load of 15,000 to 20,000 k.w. If the ash runs higher than 6 per cent nine boilers must be operated, above 10 per cent eleven boilers are required and with coal of above 18 per cent ash, nine-

[illegible]

[illegible]

[illegible]

[illegible]

teen or twenty boilers are required.

The extent to which these various items of waste enter into power plant operation may be summarized as follows:- In order to maintain a given output of power and take care of a given peak load requirement, the use of coal containing 20 per cent ash requires twice as many boilers as will coal of 8 per cent ash, 70 per cent more coal has to be purchased, 70 per cent larger freight bills have to be paid, 70 per cent more coal has to be handled and fired, and three times as much boiler ash has to be disposed of.

These two specific cases, the one of a use of bituminous coal for fuel, and the other the use of a coal for metallurgical coke will serve to show the great losses incurred through the use of coal containing an excessive proportion of dirt.

In any case the ash constitutes an extra bulk and weight of worthless material which makes extra expense every time the coal is moved, stored, or handled in any way. Generally speaking, the loss due to this cause alone is sufficient to pay the cost of washing. The saving of this waste and the increased fuel value of the washed coal is enough to justify a sufficiently higher price above that of the raw coal from which it is produced to compensate the mine operator for the expense of operating a washery and for the loss of tonnage in the refuse, providing reasonably clean refuse is made.

CHAPTER II

THE COMPOSITION OF COAL AS IT EFFECTS WASHING

4. Structure of the Coal Bed. Generally speaking a bed of coal is laid down in more or less distinct and separate horizontal layers or benches, adjacent benches being separated by the natural bedding planes, which probably represent a temporary interruption in the deposition of the vegetable matter which formed the coal. Sometimes a layer of mineral matter is deposited between benches of coal in the bed. Such a sheet of foreign matter may be only a thin coating of clay which was deposited on top of the lower bench before the layer of coal above was laid down or it may be of sufficient thickness to separate the coal deposit into two beds which must be mined separately.

Between the well defined bedding planes which separate the deposit into benches the coal appears to be made up of horizontal layers of material of somewhat different structures appearing on a vertical section as alternating bands of bright shiny jet black coal and dull coal. These layers vary in thickness from a small fraction of an inch up to several inches. This banded structure is shown in Fig. 2, a photograph of a lump of coal from the No. 6 bed near Benton, Illinois.

These alternating layers of bright coal and dull coal are designated respectively as anthraxylon and debris by Thiessen[1], who has shown by microscopic examination that they are entirely different in structure.

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[1] Structure in Paleozoic Bituminous Coals; Bureau of Mines Bulletin 117.

Fig. 2 - Specimen of Illinois No. 6 Coal Showing Banded Structure

"The bright coal bands represent parts of definite components of the woody parts of plants; that is, parts once logs of stems, branches, twigs, and roots, but now much compressed." The dull coal layers are composed of very thin discontinuous strips of bright coal imbedded in a ground mass of finely divided material, the atritus resulting from the disintegration of vegetable matter in the formation of the coal deposit. This banded structure has been recorded and discussed by various investigators since the time of Witham[1] who was the first to study coal in thin sections.

Very thin layers of charcoal, highly carbonized woody matter, are found on the cleavage surfaces parallel to the bedding planes of the coal. Ordinarily these are so thin as to be hardly discernible in the vertical section, but occasionally charcoal layers of appreciable thickness up to several inches, are found. These appear on the vertical face of the coal as, charcoal or mother of coal bands.

In addition to the division of the coal beds into horizontal layers most beds show one or more series of parallel vertical planes of cleavage which determine in a general way the direction in which the coal face breaks in mining. Subsidiary to this major system of vertical cleavage planes or fissures in the coal, which is often characteristic and continuous throughout a given seam, the coal in place is traversed locally by a more or less uniform network of planes of weakness generally referred to as joint cracks or joint planes, which determine to a certain extent the size and shape of the particles which the coal naturally breaks

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[1]Report of First and Second Meetings British Assoc. for Advancement of Science 1831 and 1832.

into when crushed. This sometimes has considerable significance in the washing of the coal, particularly if the impurities consist chiefly of mineral deposits in the various types of fissures described, of if the cleat is such that the coal and the interbedded impurities break into particles of different sizes and different shapes. In some coals this tendency is sufficiently developed to make possible a measure of separation between clean coal and dirtier coal by screening out certain sizes. An example of this is shown in the following table giving the percentages of ash in various sizes of coal screened out of a sample of raw coal at an English washery.[1]

TABLE 2

Raw Coal Screen Analysis

Size inches	Per cent ash	Size inches	Per cent ash
$2\frac{1}{2}$ - $2\frac{1}{4}$	16.01	1 - $\frac{3}{4}$	10.03
$2\frac{1}{4}$ - 2	16.42	$\frac{3}{4}$ - $\frac{1}{2}$	15.41
2 - $1\frac{3}{4}$	11.97	$\frac{1}{2}$ - $\frac{1}{4}$	16.89
$1\frac{3}{4}$ - $1\frac{1}{2}$	15.83	$\frac{1}{4}$ - 1/10	16.67
$1\frac{1}{2}$ - $1\frac{1}{4}$	13.16	1/10 - 0	20.85
$1\frac{1}{4}$ 1 1	8.75		

The structure of the coal bed and particularly the way in which the impurities are incorporated into the coal deposit has an important bearing on the washability of the coal. Most of the coarse, removable particles of refuse in a raw coal, as crushed and prepared for washing, are the broken fragments of interbedded or subsequently deposited sheets or veins of mineral matter, shale,

[1]Impurities in raw coal and their removal, - Drakeley, Coal Age, July 24, 1919.

slate or pyrite, occurring in some of the above described cracks or fissures of the coal bed.

In general the impurities break irregularly into pieces of various sizes and shapes. The coal,while forming also many irregular particles of all sizes down to the finest dust,has more of a tendency to separate along definite cleavage planes forming a larger proportion of cubes and prisms than the shale and slate with, as a rule, fewer flat pieces.

The first breaking up of the coal bed occurs during mining, primarily by separation along the principal bedding planes into horizontal benches, which at the same time break up into blocks or lumps by parting at the well defined vertical cleavage faces. This is, of course, accompanied by the formation of more or less dust and irregular broken sizes of coal.

Then, in crushing preparatory to washing there is a certain tendency,more pronounced in some coals than others, to separate along the minor bedding planes, the boundaries between the dull coal and the bright coal layers, and at the joint cracks perpendicular to the bedding. This is not intended to advance the idea that coal breaks only along these definite lines, but there is a decided tendency, as described, and consequently the detail structure of the coal determines, in a measure, how the coal breaks and what is more important, whether the coal and the dirt break free from each other.

If the impurities in the coal consist mainly of mineral deposits in these various cracks or fissures along which the coal tends to separate, they will generally be exposed when the coal is crushed, and the chances of a large proportion of the dirt parti-

cles becoming detached from the coal are favorable. In many cases the natural cleavage is between the coal and the dirt so that they break apart easily and cleanly. On the other hand the coal and the dirt may stick fast together so that it is easier to make the fracture in the coal or in the dirt part than at the contact. This results in particles part clean coal and part dirt. Fortunately the latter condition is not as common as the former. A coal in which the impurities generally stick fast to the coal in this manner is thereby rendered very difficult to wash. A coal, which is principally debris or in which the laninae are very thin, is somewhat more difficult to wash than one containing a large proportion of bright coal. The dull coal breaks more irregularly and more finely than the bright coal, which forms a comparatively large proportion of approximate cubes. In general the higher ash parts of the coal break into smaller particles than the cleaner coal. For this reason and because of the large proportion of slime formed from the clayey impurities, the highest percentage of ash is found in the fine coal or slime where it is the most difficult to remove. This is illustrated in Table 2, which shows that in the particular coal examined the material which passed through a 1/10 inch screen contained twice as much ash as some of the coarser fractions.

5. Chemical Forms of Impurities in Coal. As already pointed out in the introduction, the chief concern in washing a coal is in the removal of the sulfur and the ash forming minerals.

The sulfur in coal occurs in three chemical forms, namely, in chemical combination with iron as the bisulfide, marcasite or pyrite (FeS_2); as a calcium and sulfur compound gypsum ($caSO_4.2H_2O$); and as an organic compound in combination with the carbon of the

coal. In addition to these forms some coals may contain minute quantities of free sulfur, but this is exceptional.

The pyrite and gypsum also contribute to the formation of the ash remaining after the coal is burned. The greater part of the ash, however, is derived from the earthy minerals, clay, shale, or slate, which were deposited as mud or silt in the swamp with the vegetable matter which formed the coal. These vary in composition in different seams and different localities in the seam. The soft fire-clay deposits are usually a comparatively pure clay, consisting of Kaolin ($Al_2O_3.2SiO_2.2H_2O$) and a little fine quartz sand. The shales and slates are similar, but with varying amounts of other substances such as the oxides of iron, manganese, calcium and magnesium intermixed. The layers of shale or slate occurring as partings between benches of the coal generally, though not always, contain some carbon which gives them a dark color. The black shales, which contain a large proportion of carbon, are commonly called carbonaceous shales.

The other ash forming constitutes of coal are the residual mineral matter or ash from the original plants which formed the coal; and calcite, the carbonate of calcium ($CaCO_3$).

Some other impurities which are not of direct interest in connection with coal washing are moisture, oxygen, phosphorus, and in some coals, small percentages of alkaline salts. The moisture in coal is of course increased rather than decreased by the washing process. The phosphorus content may be reduced somewhat as it is ordinarily associated in some way with the mineral matter or at least it remains with the ash after burning. The phosphorus content of a coal is a serious consideration if it is to be used for

metallurgical coke. Where soluble alkaline salts occur they may be removed in part by washing. Salty coals are evidently not common in America, as no mention of salts in coal has been met with in the American literature on the subject. This must be a common impurity in English coals, however, W. A. Bone says on this subject, "Some coals, besides containing insoluble mineral matter, are impregnated with minute quantities of soluble salts, principally the chlorides of sodium potassium and magnesium and are thus called salty coals".

6. Physical Forms of Impurities in Coal. In the problem of efficiently cleaning a coal the physical form in which the impurity occurs has a much more important bearing than its chemical composition. As has already been pointed out the extent to which a coal can be improved by washing depends very largely upon the structure of the coal and the way in which the impurities are incorporated into the coal deposit.

For practical purposes in a study of coal washing methods, the impurities in coal may be classified as regards physical form into two groups. First, finely divided impurities structurally a part of the coal and inseparably mixed with it; and second, coarser segregated impurities, which may be separated from the coal by mechanical means.

IMPURITIES STRUCTURALLY A PART OF THE COAL

Impurities of this type are not separated by washing from the coal substance with which they are intimately mixed. The advantages of a knowledge of these constituents of a coal are all negative. The chief value of their quantitative determination is that they fix a minimum ash and sulfur content of the cleanest portion of the raw coal, which is generally called the true, fixed,

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normal or inherent ash and sulfur of the coal. In the washing process for reducing the percentage of impurity these values for inherent ash and sulfur may be approached as a limiting minimum.

The common impurities of this group are organic sulfur, fine disseminated grains of pyrite, finely divided clay, and the mineral matter of the original plants. An approximate determination of the inherent impurities is often made by crushing the coal to one-half inch or one quarter inch size and immersing it in a heavy solution which will float the coal but allow the heavier minerals to sink. Analysis of the float product then give an indication of the percentages of inseparable ash and sulfur in the coal. Some writers have erroneously designated the sulfur determined in this way as the organic sulfur content. Powell and Parr[1] have developed accurate methods for determining quantitatively the different forms of sulfur in coal and their work has made it possible to determine the percentage of organic sulfur. This is of great value in examining a coal to determine its washability as a careful sampling and analysis suffices to determine the natural limit of sulfur reduction which cannot possibly be exceeded by a practicable method of mechanical separation. It is conceivable that this might save costly mistakes in the design and erection of plants for washing non-washable coal.

It appears that the organic sulfur is united with two different types of coal constituent, and is classified as humus organic sulfur and risinic or perhaps more properly merely as Phenol soluble sulfur.

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[1]University of Illinois Eng. Exp. Sta. Bull. 111.

The microscopic pyrite[1] in coal consists of minute particles roughly globular in shape varying in diameter from a few microns to a hundred microns.

The proportion of the total sulfur that is in organic combination varies widely in different coals, although in any given coal the organic sulfur is much more uniformly distributed through the coal substance than is the pyritic sulfur.[2] The organic sulfur of some coals is sufficiently high to limit seriously the extent to which these coals can be cleaned of sulfur by washing.

As a result no doubt of the deposition of fine sediment in the coal forming swamps, contemporaenously with the accumulation of vegetable matter, coal contains more or less fine clayey material distributed all through it. Dr. Reinhardt Thiessen[3], microscopist of the Bureau of Mines, says that microscopic examination shows all bituminous coal to contain very fine ash particles probably colloidal in size. Plant accumulations deposited in still clear water would presumably form coal containing none of the ingrained clayey ash, but only the mineral matter of the plants themselves. Other layers of the bed, however, which may have been deposited during a period when conditions in the swamp were different and slimy mud became mixed with the organic matter, contain varying proportions of clay.

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[1]Theissen; Occurrence and origin of finely disseminated sulfur compounds in coal A I M E Bull. 153, Sept. 1919.

Iwasaki; A Fundamental Study of Japanese Coals, Technical Report No. 2. Tohoku Imperial University.

[2]Distribution of the forms of Sulfur in the coal bed, Yancy & Fraser.

[3]Personal communication.

As would appear logical in view of Thiessen's definitions of bright and dull coal, the dull coal, being a heterogeneous accumulation of plant degradation products in a finely divided state, contains as a rule more of this ingrained ash than the bright coal, which represents larger woody fragments in their entirety. Nebel[1] made ash determinations on a number of samples of bright coal and dull coal from Illinois seams and in every case found the dull coal to contain more ash than the bright coal layers of the same seam.

Coal may contain a considerable percentage of ash in this form without showing any appreciable difference in appearance from clean coal. One coal from the Pond Creek field in Kentucky, which was examined as to washability contained 34 per cent ash, practically all in the form of fine clay disseminated through the coal, there being little or no visible segregated impurity. Coal which contains an unusual amount of ash in this form is slightly gray in color and lacks the luster of purer coal. When it occurs as a separate layer or bench in a seam of clean coal, it is comparatively easily distinguishable by the contrast. Such coal is called bone or boney coal. Considering the way in which coal was formed it is logical to assume that there might be deposited mixtures of fine mud and vegetable attritus in all proportions grading from the clean coal on one extreme to pure shale on the other, and it is probable that samples representing such a series might be collected. Those samoles in the series which contain too much ash to be of any fuel value would be called carbonaceous shale, which belongs in the other group with the segregated impurities. There is no definite

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[1]University of Illinois Engineering Exp. Sta. Bull. 89.

natural dividing line between dull coal and bone coal or between bone coal and carbonaceous shale. Probably the most satisfactory arbitrary classification would be to designate coal of the debris structure, which is clean enough to include in the first class salable coal, say up to 12 per cent ash, as dull coal. Coal, which is too high in ash to include in the regular marketed grade of coal and yet too good to throw away, might be classed as bone coal, and that which is dirty enough to be discarded without question may be designated as carbonaceous shale. The all important characteristic of this series of impurities is that the ash is very finely divided and inseparably mixed with the combustible material. This is well shown by the results of some cleaning tests made on the Pond Creek coal mentioned above using the Trent process of oil coagulation. This process consists essentially in grinding the coal in water to about 200 mesh size and then agitating with half as much by weight of crude oil as coal until the oil and coal coagulate in a semi-solid mass rejecting the water, which carries in suspension the free detached earthy particles of the coal.

Tests on the Pond Creek coal, which was of the boney type, gave almost completely negative results, the water which separated out on several washings of the same sample carrying altogether less than one per cent of the total ash in the coal. This would indicate that even when almost all the coal is crushed to minus 200 mesh size the ash particles are still included in or attached to particles of coal.

The other important source of inherent ash in coal is the mineral matter in the original plants. Wood in its normal state contains on an average about one per cent ash; but since the plant

remains, in the process of coalification, are subject to great losses of organic matter, without a proportionate loss in the mineral part, the ash from this source in the coal may amount to a much larger percentage than in the original vegetable matter.

The total inherent ash, of all these forms, varies widely in different coals. The Pond Creek coal, already cited containing 34 per cent ash, is probably a sample of about the maximum which would be designated commercially as coal. Some of the eastern coals probably contain as low as 2½ per cent of inherent ash, and small fractions which contained less than this have been separated out of coal samples by floating on solutions of 1.20 or 1.25 specific gravity[1].

SEGREGATED IMPURITIES

This group will be considered as including all bodies of impurity which are physically distinct and separate from the coal substance. Carbonaceous shale deposits belong to this category, but because of its relation to the other substances, dull coal and bone coal in the series of clay-coal mixtures, it was described with them. A particle of carbonaceous shale may be considered in its entirety as an impurity since it has no fuel value and is essentially a shale, containing, incidentally as an impurity, some carbon.

The principal impurities which occur in coal as separate, distinct bodies are shale, clay, pyrite or marcasite, calcite and gypsum. Broadly speaking, they occur in the raw coal in one of

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[1] The Distribution of Mineral Matter in Coal,- R. Lessing, Colliery Guardian, Jan. 28, 1921.

three physical forms, namely, as layers deposited between the benches of coal in the bed, as infiltrations deposited in crevices in the bed subsequent to its formation, or as extraneous impurities, usually from the roof or floor, introduced during mining.

Shale generally occurs as layers interbedded with the coal. Pyrite also occurs in this form. In the Illinois No. 6 coal a continuous sheet of mineral matter called the blue band is usually shale; but in some places it is pyrite, and in other places shale and pyrite mixed. These layers appear in a vertical face of coal in the mine as continuous horizontal bands and for this reason they are called shale or pyrite bands. Those which separate easily from the coal are called partings and those which stick fast to the coal are usually called binders although the two terms are often used indiscriminately. The bands vary in thickness from almost nothing up to a sufficient thickness to divide the coal into two separate beds. Those which are as much as half an inch in thickness are partially removed by the miner if they are firm enough to withstand shattering during mining. The thinner bands and small fragments of the larger bands are mixed too thoroughly through the broken coal to be removed by hand. The washability of the coal depends in a large measure on the physical characteristics of the shale bands. Where most of the ash of the coal is in the form of numerous thin and friable layers of shale washing is difficult. Some of the shales occurring interbedded with coal have the property of disintegrating rapidly in water to form a soft mud. This also causes great difficulty.

The infiltrations are usually pyrite, calcite or gypsum. This is the typical form for the latter two minerals and probably

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the commonest method of occurrence of pyrite. The calcite and gypsum occur in the form of thin flakes in the joint cracks and on the minor bedding faces of the coal and in very thin veinlets which sometimes give a lump of coal a crosshatched appearance. These flakes and veinlets are very noticeable because of their white color. Since they occur in very thin brittle sheets they break up very finely and are for that reason rather difficult to wash out.

Pyrite also occurs as similar thin flakes or even thinner than the calcite, as it sometimes occurs as a mere film like a coat of paint on a natural cleavage surface of the coal. This form of pyrite is often referred to as flake sulfur or float sulfur. It is very common in the Number 6 coal in Southern Illinois, and for that reason the high sulfur coal from this seam is considered an especially difficult coal to wash. It should be pointed out, however, that a very small percentage of sulfur in this form gives the appearance of a large quantity.

Bodies of pyrite in a great variety of shapes[1] are found deposited in coal beds, or in the roof or floor. The principal forms with their common names are:

1. Rounded masses called nodules or balls. These vary in size from a fraction of an inch up to several feet in diameter. The larger balls are usually in the roof protruding down into the coal. The smaller ones called nodules may be completely imbedded in the coal or in clay or shale partings in the bed.

2. Lenses, round or oval in plan and lenticular in section varying in size up to two or three feet thick and several hundred feet in greatest lateral dimension. The commonest size in Illinois coals is probably about one and a half or two inches thick by a foot across. They are some-

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[1]Distribution of the Forms of Sulfur in the Coal Bed, - Yancey and Fraser.

times called kidney sulfur. Another form much less common than the lense is similarly circular in plan, but annular or ringshaped in cross section.

3. Vertical or inclined veins in fissures in the coal bed. These are common in the Number 5 coal in the Springfield district, where they are sometimes as much as four inches thick. The miners call this form spar sulfur.

4. Small discontinuous veinlets of pyrite, a number of which sometimes appear roughly to radiate from a common center which may be a small sulfur ball. Such a group of veinlets is commonly called a cat face. In some districts this name is applied to the pyrite deposits of lenticular shape.

The spar sulfur and the veinlets of pyrite are usually more friable than the lenses, balls and thick bands and consequently these forms of sulfur are not as completely removable by washing. The structure of this kind of pyrite appears to be, in most cases, rather shelly or cellular, as though the deposit were made up of flat, thin plates laid together with spaces intervening.

Another physical characteristic, which is of importance in coal washing, is evidenced by some types of shale and pyrite bands which are called binders. While those bands, which are called partings, usually separate easily and cleanly from the adjoining coal at a definite boundary, the binders often merge almost indistinguishably into the coal above and below, so that they will not break apart as clean shale or pyrite and clean coal. The band of impurity in such a case is usually made up of a layer in the center of comparatively pure shale or pyrite with thin, parallel interlaminated bands of coal and shale or pyrite on each side, which gradually change to coal farther from the middle of the band.

In coal beds, which have a soft floor or roof which swells, the vertical fissures are sometimes filled with clay veins forced in from the floor or roof by the pressure of the overlying strata.

This is one source of the clay in coal which, due to its fineness, makes trouble in washing and indewatering the resulting slime.

The other source of fine clay in coal, aside from such veins and occasional soft shale bands which disintegrate in water, is the floor. While some coal beds do not have a clay floor most beds have, and some of it may become mixed with the coal due to careless shoveling or to undercutting in the clay in place of in the coal.

Particles of shale and rock are also introduced into the coal from the roof. The amount of dirt going into the coal from this source varies widely in different mines, as some beds of coal are immediately overlain by solid limestone or sandstone which does not break up at all, while others have a roof of friable shale, which is shattered somewhat by the blasting and pieces fall into the coal. Some shale roofs, which stand up well temporarily, begin to disintegrate rapidly on exposure to the air so that pieces scale off and become mixed with the small coal. Probably at a great many mines the quality of the coal could be greatly improved by careful mining to eliminate dirt introduced by undercutting in the floor, shooting holes that pick up clay from the floor, and shoveling up clay with the coal. This is one of the most difficult free impurities to remove by washing.

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CHAPTER III

FUNDAMENTAL PRINCIPLES OF COAL WASHING

7. Effect of Differences in Specific Gravity. It has already been pointed out in the introduction that the commonly used methods of washing coal separate the coal and the dirt by taking advantage of their difference in specific gravity. The simplest operation which illustrates the underlying principle of the process is the fall of particles through still water. If a number of particles of the same size and shape, but different specific gravities, are dropped together into a vessel of still water the heavier particles will be accelerated more rapidly and attain a higher limiting velocity than the lighter particles. Therefore, the material, when it comes to rest on the bottom of the vessel, will be stratified according to specific gravity, the heavier particles being in a layer on the bottom with layers of successively lighter particles above. One of the early washers invented by M. J. B. Marsaut[1] for cleaning coal at the Besseges Colliery in France makes use of this simple principle of a free fall through a great depth of still water by dropping a charge of raw coal into a tank of water twenty-four feet in depth and removing separately the layers of coal and refuse deposited on a cage at the bottom of the tank.

The rate at which a particle will fall through still water depends upon its specific gravity, its size and its shape. Air bubbles attached to the particle may also affect its rate of fall. Other conditions being equal a large particle falls faster

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[1]Etude sur le lavage de la homille aut mines de Besseges.-Bull. Societe Industrie Minerale, Vol. VIII, p. 387.

than a small particle; a particle of high specific gravity falls faster than one of low specific gravity and of particles which just pass through the same screen, the round grains fall faster than the long narrow grains and these fall faster than thin flat grains. Density and size also affect the rate of acceleration of the particles while they are attaining their final velocities. Of two particles, which ultimately attain the same limiting velocity, the small heavy particle reaches its full velocity more quickly than a larger particle of lower specific gravity.

Several text books on ore dressing give the derivation of mathematical expressions for the laws which govern the fall of particles in water. Herr Bergrath von Rittinger, the earliest authority on this subject, gives the formula:

$$(1)\ V = C\sqrt{D\,(S-1)}$$

Where D is the diameter of the particle
S is its specific gravity
C is a constant

This expression is derived from the fundamental formula of physics $V = \sqrt{2gh}$ by substituting for "h" the value of D (S-1). Rittinger justifies this on the assumption that the velocity of fall of a unit cube is equal to the velocity due to a head of water of unit cross section which will support the cube. The height of such a head of water is equal to the specific gravity (S) of the cube, or when the cube is falling in water this becomes S-1 and for a cube of width "D", D(S-1)

$$V = \sqrt{2gh} \text{ then becomes } V = \sqrt{2gD\,(S-1)}$$

Richards[1] says that Rittinger's constant "C" in Equation

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[1]Text Book of Ore Dressing, p. 264.

(1) seems to be made up of f 2g where "f" is a factor due to friction. For large particles falling rapidly this formula is checked approximately by experimental results. In the fall of very small particles the effect of resistance, due to the viscosity of the liquid, assumes greater importance than the specific gravity of the particle and the rate of fall follows another law known as the law of viscuous resistance. The formula as derived by Sir G. G. Stokes[1] is

$$(2)\ V = K\ (S-1)D^2$$

This formula, however, applies only in the case of very small particles. Richards[2] gives the critical sizes for quartz and galena as 0.20 millimeters and 0.13 millimeters, respectively.

Rossbach[3] determined experimentally the falling velocity of samples of an Illinois coal and of shale from the same mine recording in every case velocities lower than the velocities calculated by Rittenger's formula for average particles, but the general relation of velocity to size of particles was approximately the same in the experimental results as in the calculated results, that is, when velocity of fall was plotted against size of particles the experimental curve and the curve of calculated values were parallel, but the experimental curve showed consistently lower velocities. Richards[4] secured similar results in experiments with anthracite,

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[1]Mathematical and Physical Papers, 1901, Vol. III.

[2]Text Book of Ore Dressing, p. 264.

[3]Washing of Illinois Coals, 1912 Thesis, University of Illinois.

[4]Development of Hindered Settling Apparatus, Trans. Amer. Inst. Min. Eng., Vol. 41, p. 396.

indicating that the curve expresses the general law closely, but the values of the constant C are not correct for the light minerals like coal. The figures commonly given for the specific gravity[1] of coal and its impurities are as follows:

Fresh Bituminous Coal	1.20 - 1.30
Shale	2.6
Gypsum	2.3
Pyrite	4.7 - 5.1

8. Settling Ratios. While these mathematically derived laws do not completely explain all the phenomena which take place in the washing operation they are sufficient to show the underlying principle of the hydro-separation of minerals. They explain why particles of different specific gravities may be separated from each other providing the range of sizes is not so great that the smallest particles of high specific gravity and the larger particles of low specific gravity fall together. The ratio of sizes of particles, which according to Rittinger's law, will fall together, may be calculated by substituting the specific gravities of the two materials in the formula, equating and solving for D diameter of particles.

$$V_1 = K\sqrt{D\ (S_1-1)} \qquad V_2 = K\sqrt{D\ (S_2-1)}$$

$$K\sqrt{D_1(S_1-1)} = K\sqrt{D_2(S_2-1)}$$

$$D_1(S_1-1) = D_2(S_2-1)$$

$$(3) \quad \frac{D_1}{D_2} = \frac{S_2-1}{S_1-1}$$

This equation gives the ratio of sizes of particles of specific gravities S_1 and S_2 which will settle at the same rate in

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[1] Specific Gravity Studies of Illinois Coals, Merle L. Nebel, Eng. Exp. Sta. Bull. 89.

still water. This is called their free settling ratio. Considering coal of 1.25 specific gravity and shale 2.70 specific gravity this ratio is $\frac{2.70 - 1}{1.25 - 1} = 6.8$

The ratio of sizes of equal settling particles of coal and shale secured experimentally by Rossback check the formula closely. These experiments were on coal of 1.21 specific gravity and shale of 2.58 specific gravity. The settling ratio determined by experiment and the ratio by calculation are as follows:

Experimental average for particles above .03" diameter	7.0
Calculated ratio	7.5

This indicates that, theoretically, with a raw coal in which the largest piece of clean coal is not more than seven times as large as the smallest particle of shale a clean separation can be effected, but if this ratio is exceeded the fine shale will remain with the clean coal.

9. The Natural Middling Product in Raw Coal. The particles in raw coal which are to be separated are clean coal on the one hand and shale, pyrite, calcite and gypsum on the other. The fact that these four impurities are all much heavier than the clean coal makes the removal of particles of pure refuse comparatively simple unless they are very small, but the separation is always rendered more or less incomplete, because of the presence of mixed particles, part coal and part refuse, which are not broken apart in crushing. Such particles, of course, are intermediate in density between clean coal and clean dirt. A third class of raw coal particles which give great trouble in washing consists of broken fragments of bands of bone coal or light carbonaceous shale. These particles also are intermediate in density between clean coal and

clean refuse. The mixed particles and the bone coal and carbonaceous shale particles form the bulk of the middling or secondary product at the washeries. This product is either crushed to finer size and rewashed or used around the plant for fuel. If there is a considerable proportion of this kind of material in a raw coal it is very troublesome for two reasons. In the first place, such particles are very difficult to separate from the clean coal and in the second place, if they are removed, it results in a large reduction in the amount of coal produced for a comparatively small improvement in ash and sulfur content. This constitutes what is probably the greatest difficulty which is met with in washing coal. It is particularly serious in many central district coals which contain, when crushed to the size at which coal is commonly washed, a relatively large proportion of such material. It would seem that the mixed particles might be eliminated by crushing fine enough to break the coal and the shale apart, but the practical value of this expedient is problematical. The effect of finer crushing in the operation of washing depends upon two opposing tendencies. First, the more finely a raw coal is crushed, the more completely will the particles of impurity be detached from the particles of clean coal. Second, the finer a coal is crushed, the more difficult it becomes to separate all of the detached particles of clean refuse from the particles of clean coal.

The bone and carbonaceous shale cannot be cleaned, as the fine ash is inextricably mixed with the coal and cannot be separated even by fine crushing. It is, however, possible to remove such particles entirely and discard the coal as well as the ash. Specific gravity analyses of two coals are shown graphically in Fig. 3.

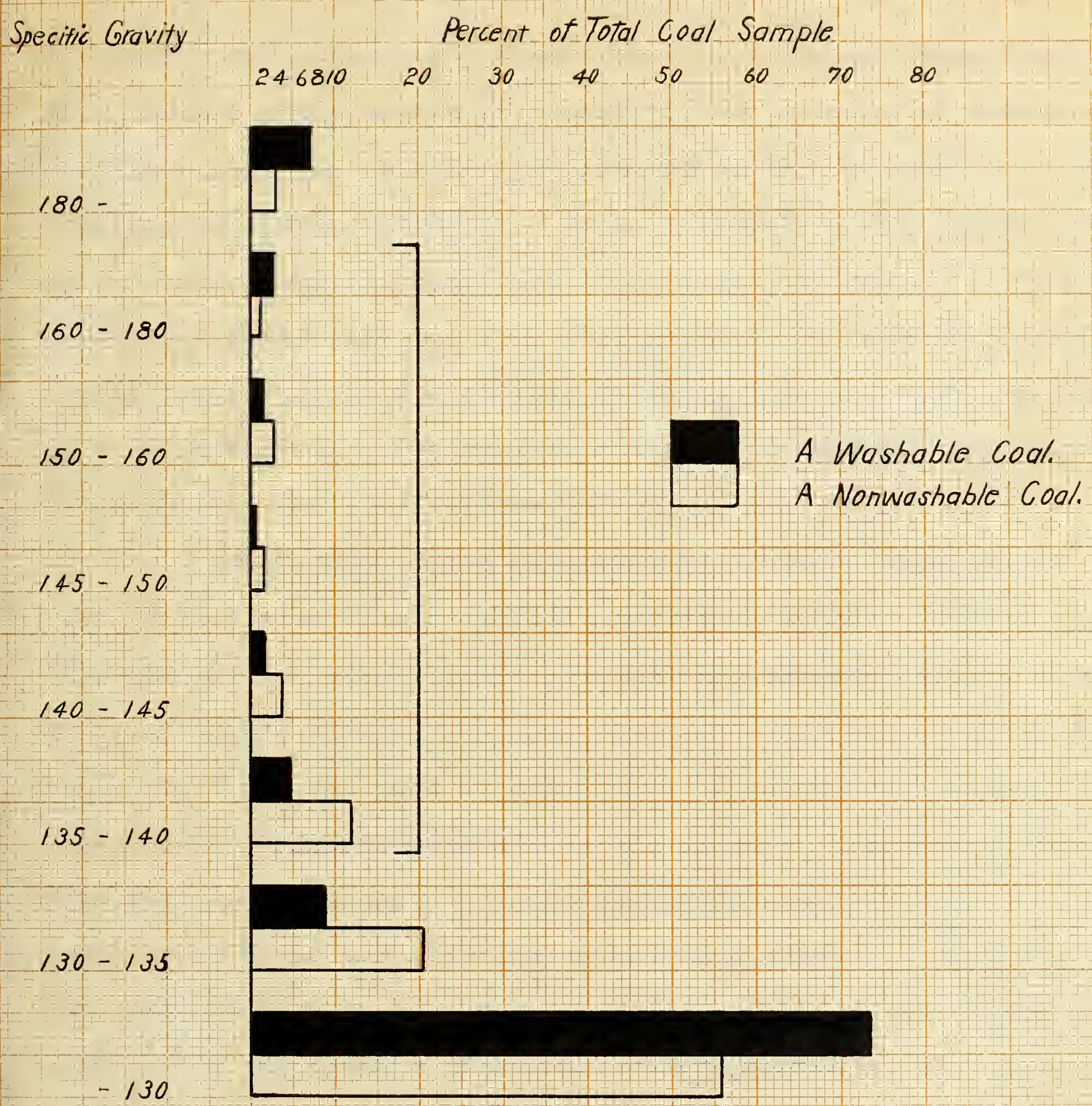

Fig. 3 —Specific Gravity Analyses of a Washable and a Nonwashable Coal.

These show the percentages of material of different densities in raw coal crushed and prepared for washing. The lengths of the horizontal lines show the relative proportions of the increments of the specific gravities indicated. Those included in the bracket make up the natural middling product which gives difficulty in washing. It will be noted that the coal designated as non-washable contains a much larger percentage of this material than the washable coal. This difference in percentage of natural middling explains in a large measure their difference in washability.

These graphs show plainly that raw coal consists of a mixture of particles of all specific gravities between that of clean coal and that of clean refuse and that no definite natural line of division exists between the coal and the refuse on the basis of specific gravity. The zone of separation in actual coal washing practice corresponds approximately to the middling zone marked out by the brackets, or perhaps a little narrower, say from 1.35 to 1.60 in specific gravity, but shifting up and down somewhat, depending upon the grade of washed coal being produced. The ash and sulfur percentages in the various fractions of different densities in these coals are shown in Table 3.

TABLE 3

Specific Gravity Analyses of a Washable and of a Non-washable Coal

Specific Gravity	Washable Coal: Per Cent of Total Sample	Washable Coal: Ash Per Cent	Washable Coal: Sulfur Per Cent	Non-washable Coal: Per Cent of Total Sample	Non-washable Coal: Ash Per Cent	Non-washable Coal: Sulfur Per Cent
- 1.30	73.35	4.64	1.72	55.9	10.1	2.91
1.30 to 1.35	8.74	11.27	2.14	20.5	13.3	3.35
1.35 to 1.40	4.93	17.78	2.39	11.8	15.4	3.45
1.40 to 1.45	1.82	20.32	2.52	3.8	19.1	4.39
1.45 to 1.50	0.39	24.60	2.62	1.8	22.5	6.18
1.50 to 1.60	1.12	29.90	2.80	2.1	27.6	9.29
1.60 to 1.80	2.13	49.53	3.43	1.1	42.7	13.30
1.80-	7.52	84.04	13.63	3.0	60.5	34.12

10. Relation of Specific Gravity and Ash Content of Coal. This table giving the ash content of fractions of the same specific gravity in different products from the same coal sho that a definite relation exists between the specific gravity of raw coal particles and their ash content. It will be noted that in a given coal fractions of the same specific gravity have practically the same ash content. The coal samples were divided into these various parts by immersing in a zinc chloride solution of 1.25 specific gravity and pouring off the float then immersing the sink in a series of heavier solutions varying in specific gravity up to 1.80 and analyzing each float product separately.

In 1893 E. B. Coxe, in an address before the New England Cotton Manufacturers' Association, stated that there is without doubt a close relation between the specific gravity of coal and its percentage of ash. A great number of specific gravity determinations and analyses made at his laboratory at Drifton, Pennsylvania,

led to the conclusion that for a given size of coal from a given mine, a specific gravity determination on an average sample will give very nearly as accurate an indication of the ash content as will incineration, although the relation between ash and specific gravity may not be the same for different coals or different sizes of coal. Nebel[1] gives the figures for ash content and specific gravity of a number of bright coal and dull coal samples from Illinois mines showing that the dull coal in every case was higher in ash content and higher in specific gravity than the bright coal.

The curves in Fig. 4 show the relation between ash and sulfur content and specific gravity for a number of coals which were examined as to washability. The ash specific gravity curves are all practically straight lines showing a fairly uniform increase in ash content with increased density. Since the calorific value varies quite uniformly with the ash content, the relation between B. t. u. and specific gravity will also be fairly constant.

11. Relation Between Specific Gravity and Sulfur Content. The percentage of sulfur in fractions of a given range in specific gravity in a coal shows considerably more variation than the ash, yet the approximate checks were secured in the coals examined and the curve, Fig. 4, shows a comparatively uniform increase in sulfur content with increasing specific gravity. This will usually be true of high sulfur coals containing much pyrite. Low sulfur, high ash coals on the other hand, may be very erratic in this respect because the increased weight of the heavy particles may be all due to ash. Cases have been observed where the heavier material con-

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[1]Specific Gravity Studies of Illinois Coals, Eng. Exp. Sta. Bull. 89.

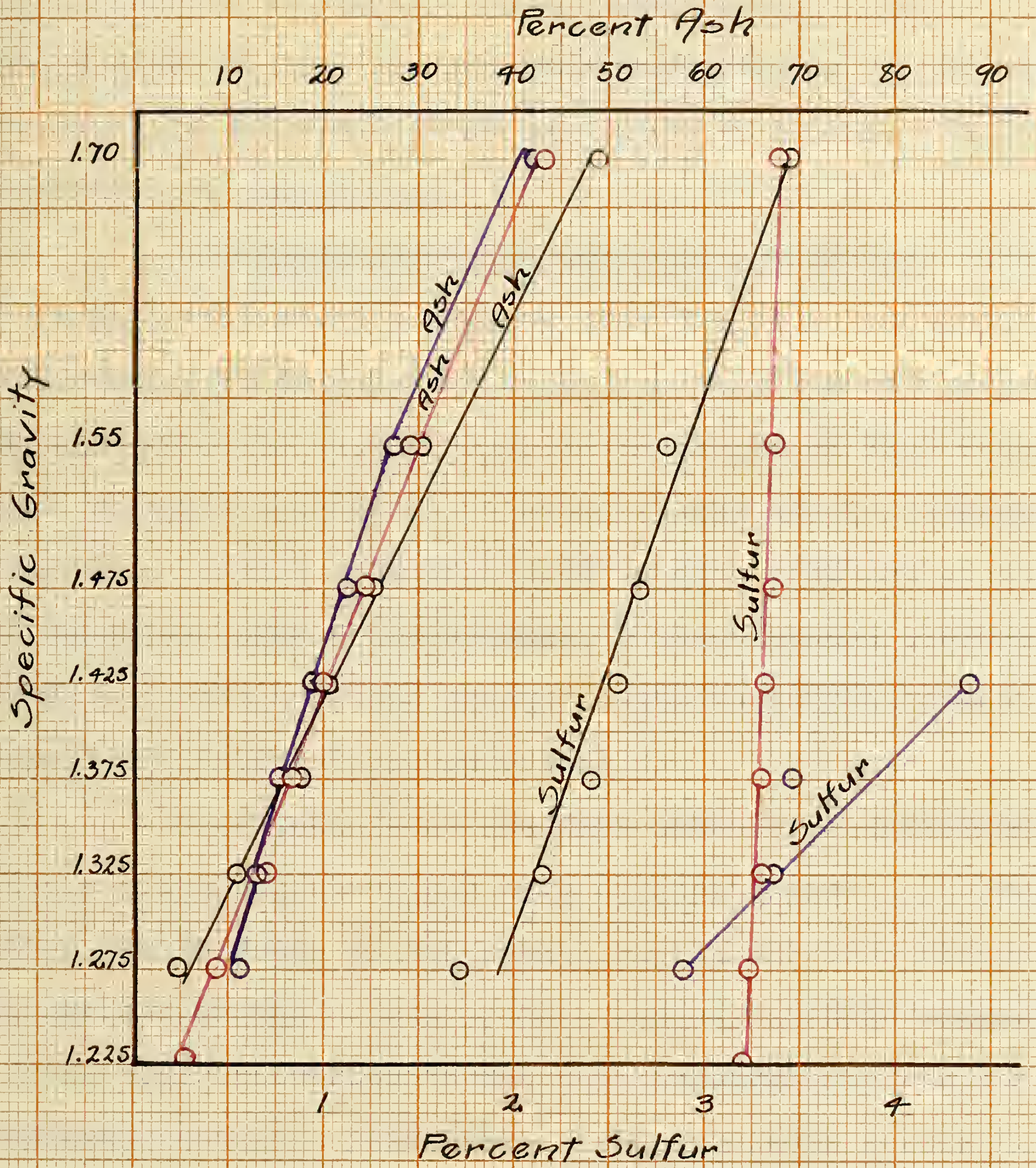

Fig. 4 – Curves showing Relation of Specific Gravity to Ash and Sulfur Content

Illinois No. 6 Coal
Bon Air Coal
Indiana Coal

tained less sulfur than the raw coal and the washed coal contained more, because the sulfur being mostly in the organic form and combined with the coal was slightly concentrated by the removal of heavy shale and slate which contained no sulfur. Such occurrences, however, are exceptional.

12. Distinction Between Coal and Refuse. Theoretically a perfect coal washing process should enable the operator to make the separation between the clean coal and the refuse product at any desired specific gravity and, as the graphs of Fig. 3 show the raw coal to contain material of every degree of specific gravity ranging from a little less than 1.25 to over 1.80 and of every degree of impurity between the minimum in the lightest product and the maximum in the heaviest product, accurate definitions of the terms "coal" and "refuse" are essential.

To formulate an abstract scientific definition of coal as distinct from refuse would be a difficult task, and would probably be of little value in the actual adjustment of a washer. It might be defined as the moisture, ash, and sulfur free combustible matter of the coal or limited to the material derived from the original vegetable material laid down to form the bed, excluding interbedded or subsequently deposited mineral matter, but neither of these definitions would be practicable for determining the standard of purity for the washed coal.

The distinction between coal and refuse as it applies to practical washery operation is purely a problem in economics which must be worked out separately for each individual operation or each new set of conditions as they are met. One of the most important considerations is the use to which the washed coal is to be put.

On this basis coal washeries may be separated broadly into two groups in which the conditions are altogether different; first, washeries for coking coal, and second, washeries for fuel coal. A washed coal which is to be made into coke for metallurgical use must meet certain hard and fast requirements in regard to ash and sulfur content and if it can be made to meet these requirements it will have a much greater unit value than if it has to be used for fuel. For these reasons, as a rule, a larger proportion of the raw coal must be, and can profitably be, discarded as refuse in washing coal for coking than in washing coal for fuel. For instance in washing either of the coals represented by the graphs of Fig. 3. If the washed coal is to be used for coking, an attempt will be made, in order to produce a good coke from these high sulfur coals, to make the separation between coal and refuse at as low a specific gravity as possible, say between 1.30 and 1.45, although some of the material discarded as refuse will, as shown in Table 3, contain only about 17 per cent ash. On the other hand if the washed coal is to be marketed as fuel the principal object of washing is to improve the appearance by removing the more conspicuous particles of pure shale and pyrite and the separation should be made at a much higher specific gravity, removing probably only the material heavier than 1.80. The increased market value added to a fuel coal by washing is not sufficient to enable the operator, without financial loss, to throw away as washery refuse any large percentage of his raw coal. This is the condition which normally exists at Illinois washeries preparing coal for the market. The economic limit on their refuse would be zero were it not for the fact that at times washing makes possible the sale of more coal or the sale of sizes

which otherwise could not be disposed of.

Within certain limits the separation between coal and refuse is under the control of the washery operator, who has two principal motives in view; namely, to produce as clean a washed coal as possible and to recover as much as possible of the raw coal in the washed product. These two objects are conflicting, and in an efficiently operated washery considerable improvement in either one can be secured only by some sacrifice in the other. Table 4 gives the results secured in a washing test on a sample of coal from the Number 3 seam in Indiana. This coal was washed on a concentrating table and separated into sixteen products varying in purity from the cleanest coal to the cleanest refuse.

This shows the purity of washed coal secured and the proportion of the raw coal which is saved in making the separation between coal and refuse at any one of the fifteen points where products were separated in this test.

TABLE 4

Recoveries and Ash Contents of Washed Coal
From a Sample of Indiana No. 3 Coal

Product Number	Per cent of Feed	Per cent Ash	Cumulative Per cent of Feed	Cumulative Per cent Ash
1	4.8	5.03	4.8	5.03
2	5.2	5.14	10.0	5.09
3	4.1	5.32	14.1	5.15
4	2.9	5.64	17.0	5.23
5	5.5	5.77	22.5	5.36
6	5.2	6.13	27.7	5.50
7	6.1	6.45	33.8	5.70
8	4.8	6.97	38.6	5.84
9	6.6	6.60	45.2	5.95
10	7.8	8.20	53.0	6.30
11	11.6	10.20	64.6	7.00
12	12.2	10.85	76.8	7.50
13	8.9	18.57	85.7	8.70
14	7.8	45.05	93.5	11.70
15	4.6	78.00	98.1	14.80
16	2.0	58.92	100.0	15.70

In Fig. 5 per cent recovery is plotted against per cent ash in the washed coal. These figures show the possible range of adjustment of the zone of separation for this coal, giving on the one extreme a maximum recovery of 100 per cent with no washing and on the other extreme a recovery of 10 per cent of the raw coal in a washed coal product of 5.10 per cent ash.

In any case the separation desired is the one that will give the largest possible recovery of clean coal which will be sufficiently pure to satisfy the requirements. This is the condition which will result in the greatest return from a given tonnage of raw coal treated.

[illegible]

Fig. 5 — Yield Ash Curve, Table Washing Test on 0" — 1/4" Coal.

CHAPTER IV

DEVELOPMENT OF THE PRACTICE OF WASHING COAL

13. First Methods of Cleaning Coal With Water. The earliest reports of the use of wet methods for cleaning coal show that from the beginning the processes and machines used for improving the quality of coal have been developed in connection with the metallurgical industries and have been brought about by the demands for better coke.

Crude methods of washing coal, by drenching it with water, were in use in Germany, France and Belgium in the first part of the Nineteenth Century. The first results recorded concern the experiments of M. Marsilly[1] with coals from the Valenciennes district. The apparatus used was called a gailleterie, and consisted of strong sieves, upon which a stream of water fell. "The largest pieces, called gailletes, about two inches in size were retained in the first sieve. The gailletins, or second size, were composed of pieces of about one-third of a cubic inch and in the third, or tails sieve, all the friable earthy and pyritious impurities accumulated." The first product was further cleaned by hand picking to remove coarse shale. This produced a good coke carrying 6 to 7 per cent ash, The second product yielded a poorer quality of coke of 7 to 11 per cent ash. In a similar process used at Commentry Colliery the crushed raw coal was flushed with water down a slightly inclined trough, with gratings placed across at intervals to retain the coarse pieces and permit the fine coal and earthy material to be

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[1]Musspratt's Chemical Dictionary, p. 94.

washed on out of the trough. A method of removing the clay or shale dust from coal by drenching it while on the screens or on the car before shipment, with a stream of water was not uncommonly used in the early days of the coal business in America. In the anthracite field especially this process was sometimes referred to as coal washing and has been confused with the specific gravity separation now designated as coal washing.

These were merely wet screening processes which, due to the fact that the refuse and the dirtier parts of the coal are usually more friable than the clean coal, makes a rough separation between the best coal and the dirty coal. An improved form of trough washer similar to that used at Commentry, but with low dams or riffles placed across the trough at intervals to arrest the flow of the heavy impurities and cause them to collect where they can be shoveled out, was commonly used until comparatively recently in the British coal fields. This was the first kind of washer in which a separation was made between coal and refuse by virtue of their difference in specific gravity.

As far back as 1826[1] a washer of this kind, then called a step washer, was used in the valley of the Tarand near Dresden Saxony for cleaning slack coal for coking. "A continuous stream of water from a superior reservoir is directed upon a flat chest, the bottom of which is formed of two steps inclined 1.5 inches per foot against the stream. The second step is lower than the first and is succeeded by a table of wickerwork or a perforated metallic sheet upon which the washed coal is drained. A low flat board across the

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[1]Coal Washing, Arthur Beckwith: Van Nostrands Mag., April, 1870.

upper end of each step serves as a dam to arrest the slate, stones and denser bodies. When these have accumulated sufficiently upon the steps the washing operation is stopped for a short time and they are shoveled out."

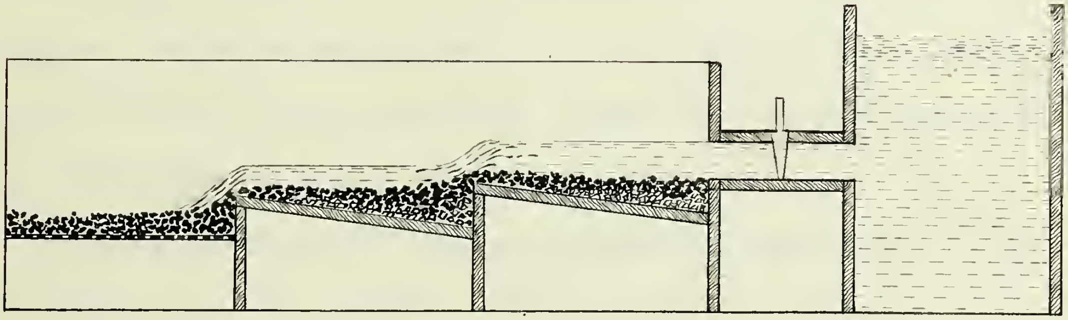

Fig. 6, Early Step Washer used in the Tarand Valley.

14. Early Hand Jigs. The first machine which made use of an intermittent rising current of water to make the separation between coal and refuse was the hand jig, a machine which was originally developed for separating metalliferous ores from their gangue rock. Agricola[1] describes a crude form of jig which was used in the Sixteenth Century. This was a round sieve bottomed basket with handles on the sides which was filled with ore and jerked up and down in a tub of water. After jigging for a sufficient length of time to stratify the particles, the lighter waste rock was skimmed off the top and discarded leaving a layer of heavy concentrate in the bottom

[1]De Re Metallica, 1556; translation by Herbert Hoover.

of the basket. Quoting from Muspratt's Chemical Dictionary referred to above, "In the pyritious coal localities of the Vosges, this process has been practised for a considerable period; but it was not adopted in other collieries till about 1840 when it was introduced into the coal districts of St. Etienne Rive de Gier and at Mons and Valenciennes". Beckwith[1] gives the date of the beginning of hand-jigging operations at St. Etienne as 1837. The first jigs used for coal washing were similar in action to that described by Agricola, but the basket was made larger and it was moved up and down in the water by means of a hand lever.

Another type of hand jig which is nearly as old as the movable sieve jig is shown in cross section in Fig. 7. This jig was in use in Germany and France prior to 1850[2].

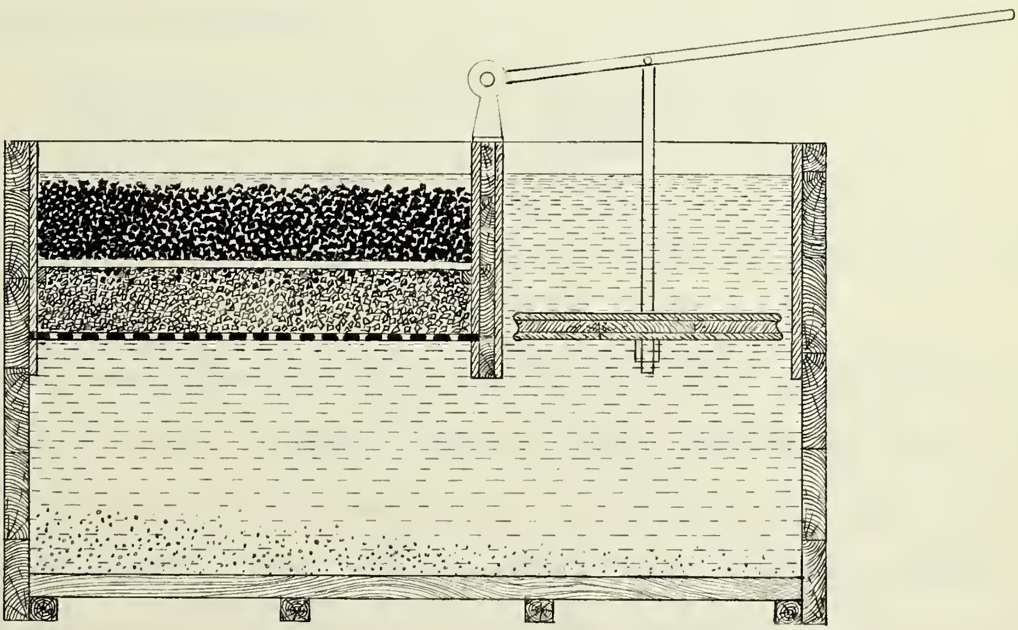

Fig. 7 - Hand Jig used in France and Germany in 1850.

[1]Loc. cit.

[2]From an unpublished manuscript by S. Stutz, owned by Professor H. H. Stoek.

The raw coal to be washed was placed on the sieve in the front compartment of the box and the piston in the back compartment was jerked up and down by means of the hand lever, imparting a pulsing motion to the water which jigs the coal above the screen and caused it to stratify with the refuse in a layer immediately above the screen. The bars shown above the screen in the washing compartment were to guide the shovel in skimming off the washed coal. One man produced with one of these jigs three-eighths to one-half ton of washed coal per ten hour day.

15. Mechanically Operated Jigs. Stutz describes the operation of a similar piston jig in which the piston was operated mechanically. This machine was in operation at the Besseges Colliery in 1855. One man tended two machines skimming off the washed coal and shoveling in the raw coal. The two machines produced fifteen to sixteen tons of washed coal per day. The ash in the various products is given as follows:

Raw coal...............	21.35	per cent
Washed coal............	7.75	" "
Refuse.................	71.65	" "
Slime in jig box.......	46.38	" "

The refuse contained 10 to 12 per cent of coal, the slime 25 to 30 per cent and the waste water 2 to 4 per cent.

Stutz describes a number of similar jigs in operation at German and French mines between 1850 and 1860, including one at the Hirschbach coking plant near Saarbruch for washing coking slack from the Saar district. The jigging compartment in this machine was six feet long by four feet wide and handled half a ton of coal at a charge.

The first coal washing jigs in which the operation was continuous and the washed coal and refuse were discharged automatic-

ally were the Meynier and Berard washers. The Meynier washer was first used at the Brassac Collieries Puy-de-Dome, France, where a plant was constructed in 1854.[1] The pulsion of water in the washing compartment was produced by a piston pump and the washed coal and refuse were carried out at the front of the washing compartment by the flow of water.

The Berard washer was similar, but the pulsion was produced by a piston working in a cylindrical compartment of the washer. This machine was exhibited in London in 1851 and in Paris in 1855. The first operating plant was build at the Mollieries Colliery in 1863.

The useof coal washing jigs of the modern type may be said to have begun with the introduction of the Luhrig jigs and the Luhrig system of washing in 1870. In 1867 Mr. C. Luhrig[2] of Dresden Saxony began experimenting with the Harz jig, which had been used for years for the concentration of lead ores in the Harz Mountains, and in a few years produced the Luhrig coarse coal jig and the Luhrig fine coal jig. These or similar jigs with minor changes in construction and operation are the most commonly used coal washers at the present time.

The Luhrig nut coal jig, (Fig. 8) consists of a rectangular box with hopper bottom having a partition in the middle, extending about half way down from the top, or to a point slightly above where the hoppering begins. Upon one side of this partition, is a relatively close-fitting rectangular piston actuated by an eccentric

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[1]S. Stutz Loc. cit.

[2]Jahrbuch fur Berg and Huttenwesen 1878, p. 85.

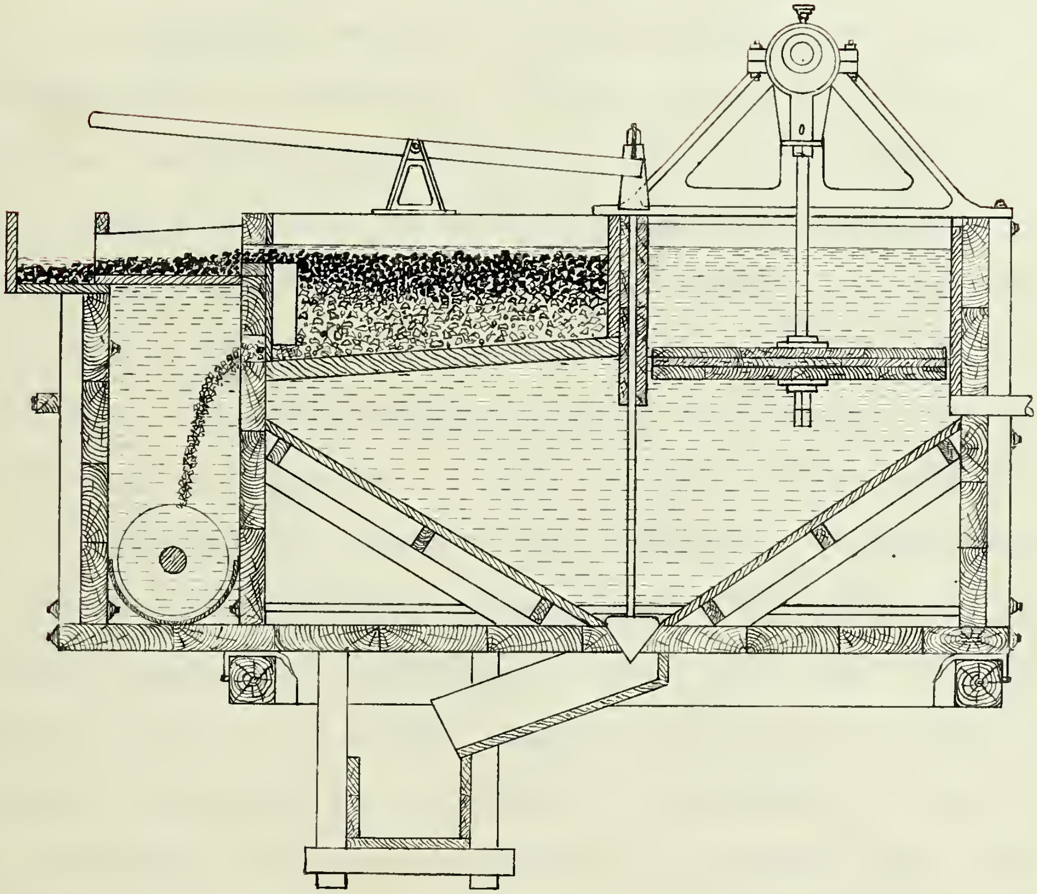

Fig. 8 - Luhrig Nut Coal Jig

On the other side of the partition there is a fixed screen which is sometimes slightly inclined away from the partition. The jig is filled with water, to which the piston imparts a pulsating motion, forcing it up and down through the screen. Sized raw nut coal is fed upon the screen near the partition and purified by the hindered settling action induced by the pulsation of the water through the screen. The washed coal flows from the top of the screen compartment at the opposite end from the feed, while the refuse works its way across and is discharged through a valve just above the screen and below the washed coal overflow. The bed is kept thin enough to permit regular and even pulsations of water through the screen, and thick enough to prevent fine coal from working through the screen by the aid of suction and entering the hoppered bottom, or hutch, of the jig. The refuse which collects in the hutch is discharged at intervals, as required, through a valve at the bottom.

The Luhrig fine coal jig, (Fig. 9), differs from the nut coal jig in three important particulars. The screen is horizontal or slopes toward the partition, an artificial bed of feldspar is provided, and all the refuse passes through the bed and screen into the hutch from which it discharges continuously. It is fed with fine coal which has been classified in a grading box. The reversal in slope of the screen is for the purpose of bringing the thickest portion of the bed near the piston where the rising current of water is strongest, thus equalizing the pulsations throughout the bed.

The essential feature of the system of washing introduced by Mr. Luhrig was the screening of the raw coal into a great number of sizes and washing each size separately. In the discussion of settling ratios of coal and refuse, it was pointed out that if the

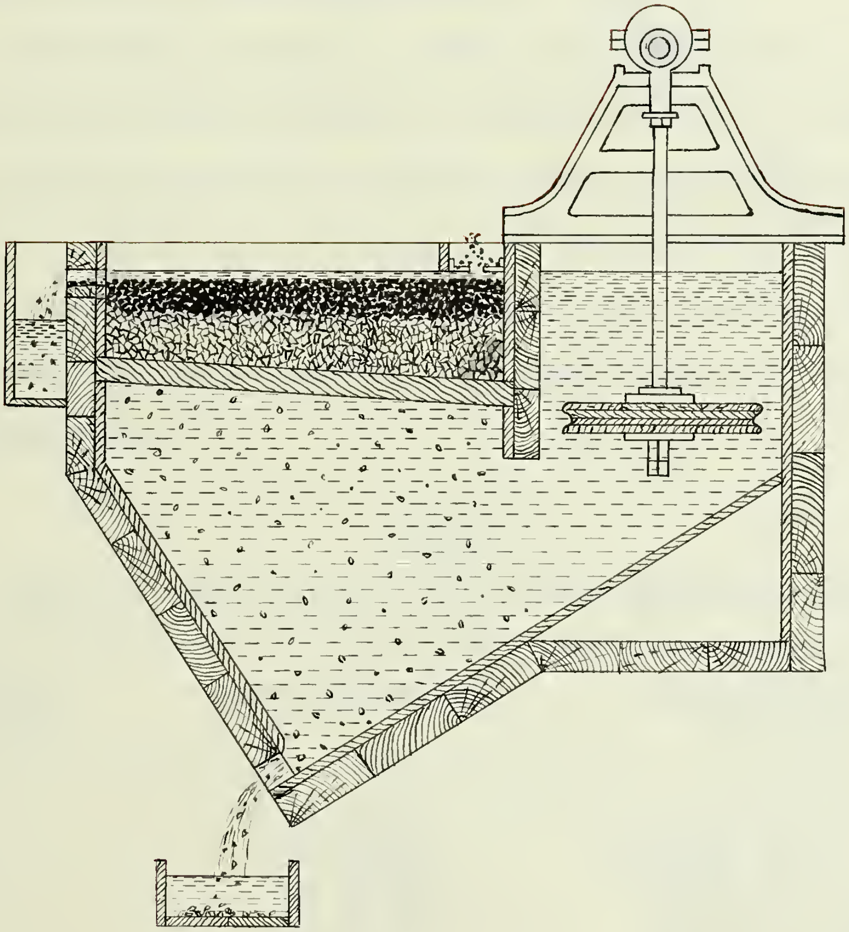

Fig. 9- Luhrig Fine Coal Jig

range of sizes of particles in the raw coal being washed was too great the fine refuse and the coarse coal particles would not be separated. In the Luhrig system the principle of sizing before washing was carried to the extreme, on the theory that the more nearly of a uniform size the particles in the raw coal are made the more complete will be the separation.

The extreme length to which this principle was carried out in the early Luhrig washers is illustrated by a large plant erected in 1880 at Reimsdorf Colliery near Zwickau, Saxony. In this plant, as described by Stutz, the raw coal was separated into nine sizes, and each size washed separately, the five largest sizes on Luhrig nut coal jigs and the four fine sizes on fine coal jigs with feldspar beds.

TABLE 5

Sizes of Raw Coal Treated At the Reimsdorf Washer

Product Number	Size Millimeters	Equivalent Size in Inches
1	60 to 70	2 3/8 to 2 3/4
2	45 to 60	1 25/32 to 2
3	30 to 45	1 3/16 to 1 25/32
4	15 to 30	19/32 to 1 3/16
5	8 to 15	5/16 to 19/32
6	7 to 8	9/32 to 5/16
7	5 to 7	3/16 to 9/32
8	2.5 to 5	3/32 to 3/16
9	0 to 2.5	0 to 3/32

16. <u>Early Development of Coal Washing in America</u>. The first record of any activity in America in the way of coal washing was the granting of patent No. 20756 to Hezekiah Bradford of Reading, Pennsylvania, for an "Automatic Coal Jig" called the Bradford jig.

There is no record of this jig being used in commercial practice, however, until years later, about 1880, when an improved Bradford jig was used in several anthracite washeries. The first actual coal washing operation[1] in America was probably in the Pittsburgh district of Pennsylvania where Jones and Laughlin had trough washers in operation for some years prior to 1870.

The first jig washer[2] of which any record is available was erected in 1869 at Alpsville, Pennsylvania, about twenty-four miles from Pittsburgh. This was a small plant with a capacity of about ten tons per hour intended to be used for washing coking slack from a group of nearby mines. It was erected by a German engineer named John J. Endres, who had been employed on similar work at the Prussian Government mines.

H. H. Stoek[3] gives the date of the beginning of anthracite washing in America as 1875, with the introduction of jigs by the Lehigh Coal and Navigation Company.

In 1870[4] samples of coal from along the Pittsburgh Railway in the Standard field of Illinois were taken to Cologne, Germany, and subjected to extensive washing tests with an Osterspey jig. The results secured were as follows:

	Ash %	Sulfur %
Raw nut coal......................	15.57	2.99
Washed coal......................	6.00	1.40
Coke from washed coal...........	10.00	1.02

Yield of washed coal 60% to 65% of the raw coal.

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[1]TAIME, Vol. 3, p. 77, Discussion.

[2]Process of Washing Coal, S. Deischer Proc. Eng. Soc. W. Pa. 23-202, May 21, 1907.

[3]Editorial in Mines and Minerals, Vol. 26, p. 478.

[4]Coal Washing in Illinois, E. E. Meier, E. & M. J. 22-88.

These results were secured by very close sizing and re-washing the washed coal. Following these tests an Osterspey jig washer was erected in East St. Louis in 1870-1871 for Adolphus Meier & Company to wash coal for coking. The Osterspey jig was very similar to the Hartz jig from which the Luhrig jig was developed, except that it was provided with a differential motion to give a quick down stroke and a slow up stroke to the piston.

During 1871 and 1872 Endres erected five more piston jig washeries, all for washing coal to be coked in a new patented form of bee hive oven called the Belgian oven, which was being widely introduced at that time, with the expectation that it would make possible the production of good coke from the low grade non-coking coals of the Middle West. One of these washeries was built at Eliza furnaces, Pittsburgh, Pennsylvania, one at Hollidayburg, Pennsylvania, one at Irondale, Ohio, one at Equality, Illinois, and one at Joliet, Illinois.

During the same period a Berard washer[1] was erected at the coke plant of the Johnstown Iron Works at Johnstown, Pennsylvania, for washing coking coal, and in 1873 another of the same type was put up in the Broadtop Region[2] of Pennsylvania by the Kemble Coal and Iron Company for washing coal from the Kelly seam. This period of washery building in the East and Middle West was brought to a close and operation of most of the early washers were suspended during the panic from 1873 to 1879, during which time the best Connelsville coke sold on the market for ninety cents per ton.

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[1]TAIME, May 1872, p. 223, Discussion by M. Pechin.

[2]Coal Washing, J. Fulton, T. A. I. M. E., Vol 3, p. 72.

In 1875 the practice of washing coal was introduced into the Southern field with the construction by the Eureka Coal and Iron Company at Helena, Alabama, of a Stutz jig washer to wash coal for coking in thirty Belgian ovens.[1] This washer is said to have been successful and was dismantled only on account of the abandonment of the mine. Due to the high ash in the Alabama coals, which are otherwise good coking coals, washing has been very widely adopted in this field. In 1904 there were thirty-three washers in operation in the state with a total capacity of 26,000 tons per day.

With the return of prosperous conditions in 1879 a second period of washery building was initiated in the Eastern and Middle Western fields which has continued down to the present time. Before 1885 five more washers were erected in Illinois for washing coal for coking, but none were successful in reducing the sulfur sufficiently to produce a good metallurgical coke and all the washers built in Illinois since 1885 have been for the purpose of washing coal for fuel up until the summer of 1918 when an extensive washing plant was erected by the United States Fuel Company at the Middlefork mine at Benton, Illinois, for washing coal to be used for coking, mixed with a large proportion of West Virginia and Kentucky coking coals.

The first washer erected in the Rocky Mountain district was a Stutz jig washer of the Colorado Coal and Iron Company at El Moro, built in 1881 to wash the Engleville coal. After several years operation this washer was abandoned because the waste in the refuse

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[1]Coal Washing in Alabama, Ramsey & Bowram, Mines and Minerals, Dec. 1904.

was excessive and a coke of 10 per cent ash could not be secured. In 1893 the Colorado Fuel and Iron Company conducted tests on this coal at the Luhrig washery of the Sloss Coal and Iron Company at Birmingham, Alabama, but the results were disappointing due to the high proportion of bone coal. An experimental Campbell table washer was then installed and operated for several months and was found to do good work, but at too small a capacity. A Forrester jig was then installed in the experimental washer and tests were made with such success that a Forrester washer was erected at Sopris in 1896.

The first Luhrig washer in America was erected at Birmingham in 1890, and in the ten years following six other washers using the Luhrig system were erected in America at Carterville, Illinois; Belt, Montana; De Soto, Illinois; Dunsmuir, Vancouver; and two near Greensburg, Pennsylvania. These washers, however, were not very successful in America due to the difficulty of operating such a complicated plant with the unskilled help usually available here. A wide spread prejudice against the practice of washing coal in general, which grew up during this period and remains more or less to the present time, was engendered very largely by the great difficulties and losses encountered in operating the early Luhrig plants in which the principle of close sizing was carried to a ridiculous extreme. The great number of screens, classifiers, elevators, conveyors, bins and jigs necessary in order to handle the various sizes separately necessitated a large capital expenditure and, in an attempt to economize, the individual machines were usually made too small and were crowded together in light wooden buildings three or four stories high, so that the plant presented the appearance of an intricate maze of elevators, conveyors, belts and shafting, which

furnished numerous opportunities for disagreeable break-downs. The complication of design was further added to by the machinery manufacturing companies who built the plants, as they were naturally desirous of disposing of as much of their machinery as possible.

While the Luhrig nut coal and fine coal jigs or similar machines are still the most commonly used form of coal washer the complicated Luhrig type of washing plant has gone out of use. It has been found that the laborious separation of the coal into eight or ten sizes is unnecessary and undesirable. The most common practice at modern American washers for coking coal is to screen the raw coal into only two sizes, or at most three sizes before washing, and at many washers preparing coal for fuel screenings ranging from three inches in size to dust are washed together in one jig with satisfactory results.

CHAPTER V

MODERN COAL WASHING MACHINERY

17. Jigs. Although a number of new developments in coal washing machinery have been introduced in recent years, the jig, in one form or another, still remains by far the most commonly used form of coal washer and will probably continue to be because it is the only method which has proven entirely successful for washing coal of the fuel sizes.

It is safe to say that, in America at least, more coal is washed on jigs than on all other kinds of washers combined. The fine size to which coal has to be crushed for treatment on concentrating tables eliminates these machines from consideration for washing coal for fuel except as auxiliary equipment for cleaning the fines.

PRINCIPLES OF JIGGING

The jig is essenitally a perforated plate or screen supported in a horizontal position with an intermittent pulsating current of water flowing through it. On the downward stroke of the plunger, the water is forced upward through the screen to a height of from six to twelve inches above the screen. On the upstroke of the piston this water flows back through the screen by gravity or is drawn down by the suction of the piston. This cycle is completed from eighty to one hundred fifty times per minute depending on the size of coal being treated.

A bed of raw coal several inches thick is maintained on the screen. On the upward flow of the water the coal particles, being lighter than the refuse particles, are carried higher, thus tending to separate from the refuse in a layer above it. On the return downward flow of the water the heavy refuse particles will fall more rapidly than the coal, thus increasing the separation. When this action is repeated a sufficient number of times the coal and the refuse are arranged in definite distinct layers on the screen, the coal above the refuse.

As explained in the chapter on fundamentals of coal washing this separating action of the jig depends upon the operation of Rittinger's law of the rate of falling of particles in water.

$$V = C\sqrt{D\,(S-1)}$$

From this law the maximum range of sizes of particles that may be successfully treated together is derived. It was early observed, however, that in actual practice a much wider range of sizes could be treated successfully than was theoretically possible, according to the free settling ratios. Several theories have been advanced to explain this.

Rittinger ascribed this excess jigging power to the fact that a small particle of the heavier mineral is accelerated more rapidly than an equal settling larger particle of the lighter mineral. A particle of pyrite for instance may attain its maximum falling velocity in one-tenth the distance required by the coal. In the succession of short falls produced in the jig this would have an important bearing. As the limiting velocity would probably not be attained by any of the particles, the rate of acceleration would largely determine the separation.

Later investigators designated as "hindered settling" the fall of particles enmass under the conditions existing in actual jigging practice where the free fall of individual particles is hindered by immediate contact with other particles. The hindered settling ratio is, as demonstrated by commercial jigging practice, larger than the free settling ratio of the same minerals. Professor Henry Louis[1] explains this as due to the fact that the small particles of the heavy mineral which, by the free settling ratio, would settle at the same rate as the larger particles of the lighter mineral, being much smaller than the equal settling light particles can slip through the interstices between the large particles and may therefore settle with less interference. Professor R. H. Richards[2] considers the falling of particles under hindered settling conditions as equivalent to free settling in a medium which is heavier than water as each individual particle must settle through a medium made up of all the other particles suspended in water.

A third idea advanced by Professor H. S. Munroe explains the large ratio of sizes that can be jigged as due to the effect of interstitial currents on the small particles. By experiments with particles falling through water in glass tubes, Munroe came to the conclusion that the rate of fall in restricted channels was altogether different from free settling and obtained an experimental settling ratio of 1:30 for galena and quartz under these conditions as compared with 1:4 for free settling conditions by the Rittinger formula. Richards checked this value by dropping a mixture of

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[1]The Dressing of Minerals.

[2]Text Book of Ore Dressing, p. 268.

small galena and quartz particles through a slowly rising current of water in a device which he called the pointed tube. This had a narrow section at the bottom. Screening tests were made on the material which settled through this narrow portion of the tube into a rubber bulb below. The ratio of the average sizes of galena and quartz found together in the bulb was 1:6. The interstitial ratio for shale and coal if increased over the free settling ratio in the same proportion would be 1:9 where the free settling ratio is 1:6.

The effect of the interstitial currents is operative on the down-flow of the current as well as the up-flow and where suction is used drawing the water down through the bed by the return stroke of the piston a classification of the fine particles will be effected in the interstices of the bed of material on the screen. This is born out in practice as it is a demonstrated fact that a natural feed of unsized coal is washed more effectively on a jig in which moderate suction is used, than on one which is especially designed with valves in the piston or a differential piston actuating mechanism to eliminate suction. On the other hand if closely sized coal is treated on a jig with suction on the return stroke of the piston, the tendency is for the particles to arrange themselves in reverse order from that desired. The coal particles being of smaller inertia than the refuse are more readily reversed in direction at the end of the up-stroke and are consequently drawn to the screen ahead of the refuse by the suction of the return stroke.

In order to utilize the effect of interstitial currents in jigging closely sized fine coal a permanent artificial bed of coarse material is sometimes placed on the screen of the jig. This acts in the same manner as the shale bed accumulated in jigging an

unsized feed. The fine refuse is drawn through the interstices of the bed into the lower part of the jig called the hutch. The material used for a bed is usually crushed feldspar having a specific gravity of 2.6 or about the same as shale. This method was introduced with the Luhrig system in 1875 and is widely used at the present time for fine coal jigging.

During recent years great progress has been made in jigging practice from the viewpoint of capacity and economy of operation. Very large plunger jigs of sixty to seventy-five tons per hour capacity are now used successfully and the cost of jigging coal has been reduced in well managed plants to very low figures. The main features of jig design and operation remain practically the same as at the first American plants built in 1870 and probably nothing in the way of an improvement has been added which appreciably increases the effectiveness of the operation so far as cleaning the coal is concerned.

JIGS IN PRESENT USE

Generally speaking, the piston jigs in present use are similar to the Luhrig jigs already described. The mechanical differences in the various makes are usually in the method of piston operation or of refuse discharge. The Lehigh, Forrester, Foust, Shepard and Coppee jigs are operated like the Luhrig by a simple eccentric motion which gives equal up and down movements of the piston.

The Elmore or New Century jig and the Baum jig aim to produce a quick down-stroke and slow up-stroke to reduce the effect of suction in the jigging compartment on the return stroke. In the Elmore jig, this is accomplished by means of a cam on the eccentric and a strong spring

which makes the rider follow the cam closely. In the Baum jig compressed air is used to produce the pulsation of the water in the jigging compartment.

Probably the newest jig of this class is the Pittsburg piston jig used at the Middlefork washery of the United States Steel Company at Benton, Illinois. In this jig the piston is horizontal and double acting, working in a vertical partition below the middle of the jigging compartment. The effect of this is to give an upwart current in one-half of the jigging compartment and a downward current in the other half.

Any of the piston jigs may be and are used with artificial beds of feldspar for fine coal treatment as in the Luhrig fine coal jigs.

The most widely used of the movable sieve jigs are the Stewart, Shannon, American and the original Pittsburgh jig. The Stewart jig is commonly used at Illinois washers. The characteristic feature of this jig is the basket or box with perforated bottom into which the material to be washed is fed and over which the current of water carries it. The entire box is suspended in a tank of water from eccentric suspension rods, which impart to it an upward and downward movement. This forces the water alternately back and forth through the perforated bottom, lifting the coal and allowing it to be carried away by the stream of water flowing from the top, while the heavier material or refuse settles on the screen plate, from which it works forward and off into the water tank through a valve set at suitable height.

The Pittsburgh pan jig differs from the Stewart in that instead of eccentrics a crank arm mechanism is used in order to

produce a quick down-stroke with a slow up-stroke and suction in the bed is still further reduced by extending the sides of the pan below the screen and inserting a solid bottom with valves which open upward, but close on down stroke preventing the water in the pan from rushing out through the screen.

The movable sieve jigs are most suitable for coarse coal and for the production of two products only, as in order to produce a third or middling product two jigs would have to be used. For these reasons their use is confined largely to the washing of coal for fuel where a large tonnage of unsized coal is to be cleaned of only the large pieces of clean refuse; although when the Stewart jigs were first introduced a large number of these washeries were built in the south for washing coking coals,

A number of the jigs described are illustrated in Fig. 10,[1] and classified as to method of operation in Table 6.

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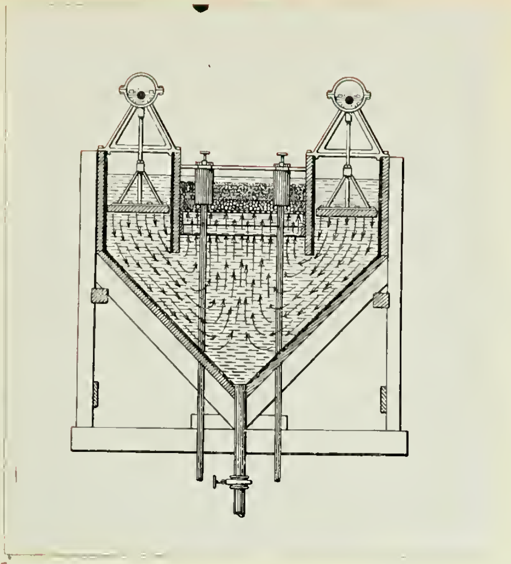
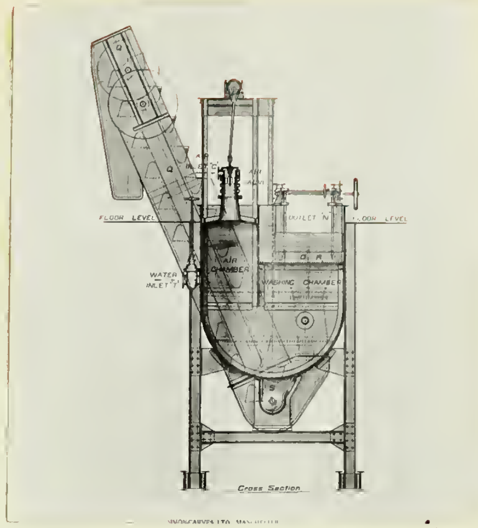
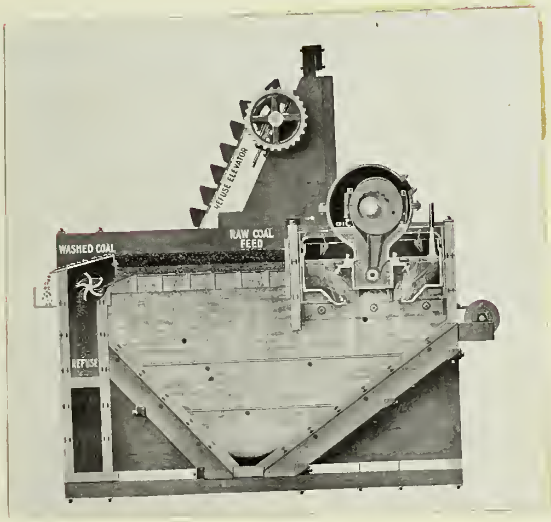
[1]From the files of the Department of Mining Engineering, University of Illinois.



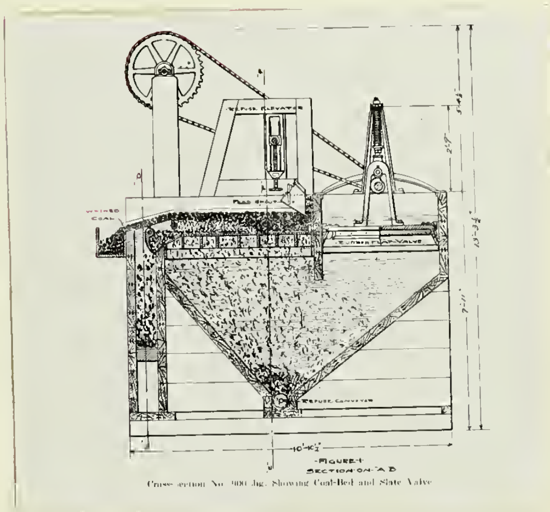
Foust Jig



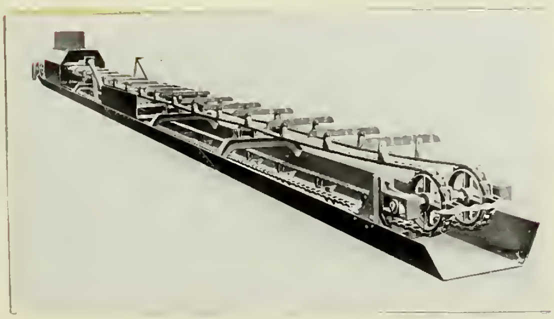
Baum Jig



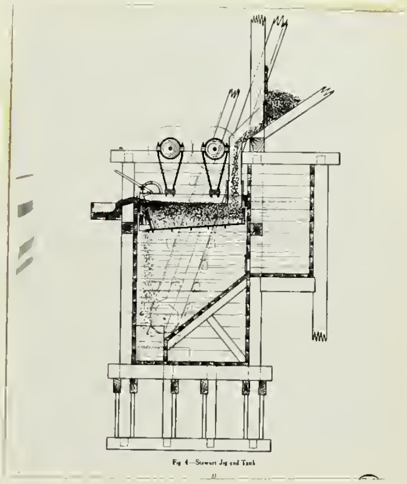
New Century 900-C



New Century 900



Elliot Trough Washer



Stewart Jig

Fig. 10 - Types of Washers in Present Use

TABLE 6

Classification of Coal Jigs

Characteristic Features	Piston Jigs	Pan Jigs
Equal pulsion and suction strokes.	Luhrig Diescher Coppee Forrester Foust Shepard Lehigh (anthracite) Pittsburgh Elmore 600A	Stewart American Shannon Simplex (anthracite) Christ
Suction reduced by differential piston or pan motion.	Elmore 500 Elmore 600 Elmore 800 Humboldt Asterspey	Pittsburgh
Suction reduced by valves.	Hoyle Montgomery Elmore	Pittsburgh (Shannon[1] (Stewart[1]
Pulsion only produced by compressed air.	Baum	

18. Trough Washers. The old hand cleaned trough washers which were so widely used in the coal fields of England and Scotland up to about 1890 are now entirely obsolete, although up till very recently some of the improved traveling riffle type were still in use in Scotland. The most common of these was the Elliot washer in which riffles were carried on a traveling endless chain which

[1]Shannon and Stewart jigs are made both with and without an auxiliary bottom, containing flat valves, below the screen.

moves the riffles slowly up the inclined trough and dumps the refuse over the upper end. This washer is similar in operation to an inclined drag conveyor-elevator. The Scaife washer manufactured in Pittsburgh, Pennsylvania, was a trough semicircular in cross-section through which the coal was flushed by a stream of water and kept agitated by rocking arms. The refuse was retained behind semi-circular iron riffles and was discharged by dumping the hinged bottom of the trough at intervals.

A revivial of interest in the trough washer is reported in Belgium with the introduction of a new modification called the Rheolaveur. This is essentially a rising current classifier attached beneath the trough and communicating with the refuse slots or the pockets behind the riffles in which the refuse is collected. The Rheolaveur is an inverted pyramidal cast iron box which fits on the bottom of the trough. In the hopper bottom is a spigot for drawing off the refuse and a water inlet pipe to produce a rising current in the slot which assists in assorting the particles dropping out of the coal stream. The Rheolaveurs are placed at intervals of about ten feet along the trough and those which draw middlings are, in some cases, discharged into another trough for rewashing. At the St. Nicholas pit of Societe Des Charbonnages de L'Esperance et Bonne Fortune near Liege, Belgium, Coppee jigs were abandoned because of the high loss of coal in the refuse and Rheolaveur trough washers have been installed. The advantages claimed are cheaper operation, no moving parts, small floor space and head room required, and simplicity of operation.

Results secured at the St. Nicholas plant referred to above are reported as follows:-

	Per cent Ash
Raw coal	26.9
Washed coal from first trough	7.3
Washed coal from second trough	10.2
Refuse first trough, first and second orifices	71.8
Third orifice	34.9
Second trough, first orifice	68.8
Third orifice, final middling	31.8

19. Concentrating Tables. Within recent years reciprocating tables of the Wilfley type have been adapted to the concentration of small coal and installations of such tables have been made at a few American washers. The Wilfley table is manufactured by the Mine and Smelter Supply Company of Denver. The machine constructed for coal washing is called the Massco table. All the manufacturers of concentrating tables have now adapted their machines to the treatment of fine coal and are manufacturing tables especially designed for coal washing.

Fig. 11 shows the small size Plato coal washing table which is manufactured by the Deister Machine Company at Fort Wayne, Indiana. The underconstruction of this table is shown in Fig. 12. The commercial size table is fourteen feet long by six feet wide. Fig. 13 shows a Deister Overstrom coal washing table in operation at the testing plant of the Deister Concentrator Company in Fort Wayne. The Butchart table and the Overstrom-Universal table have also been used, at least experimentally, for the purification of fine coal and with a fair degree of success. These tables are all very much alike in principle.

A concentrating table[1] as used in coal washing consists essentially of a linoleum covered plane surface, or deck, approxi-

[1] Coal Washing, Horatio C. Ray, Coal Industry, Nov., 1919.

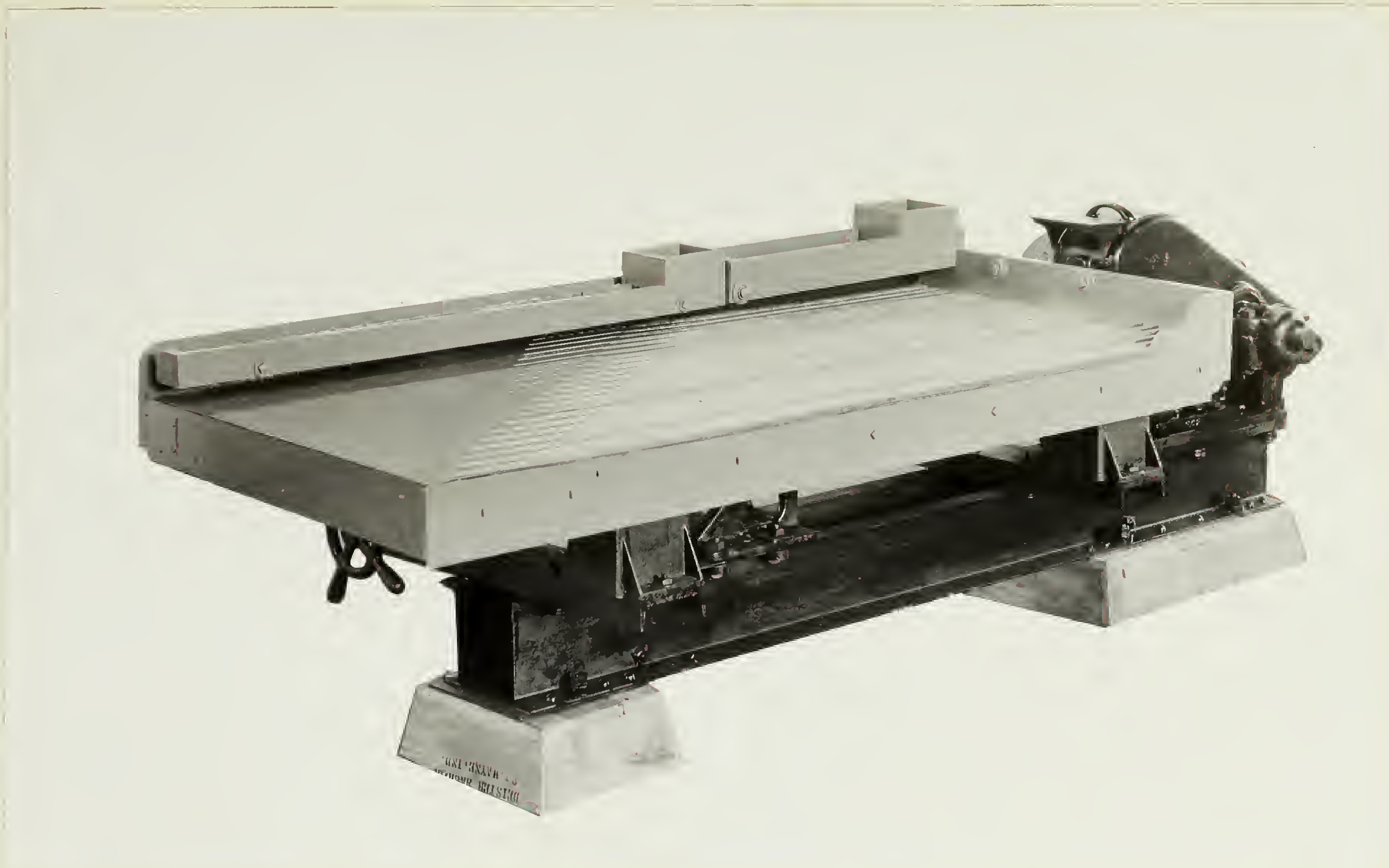


Fig. 11 - The Laboratory Size Plato Coal Washing Table

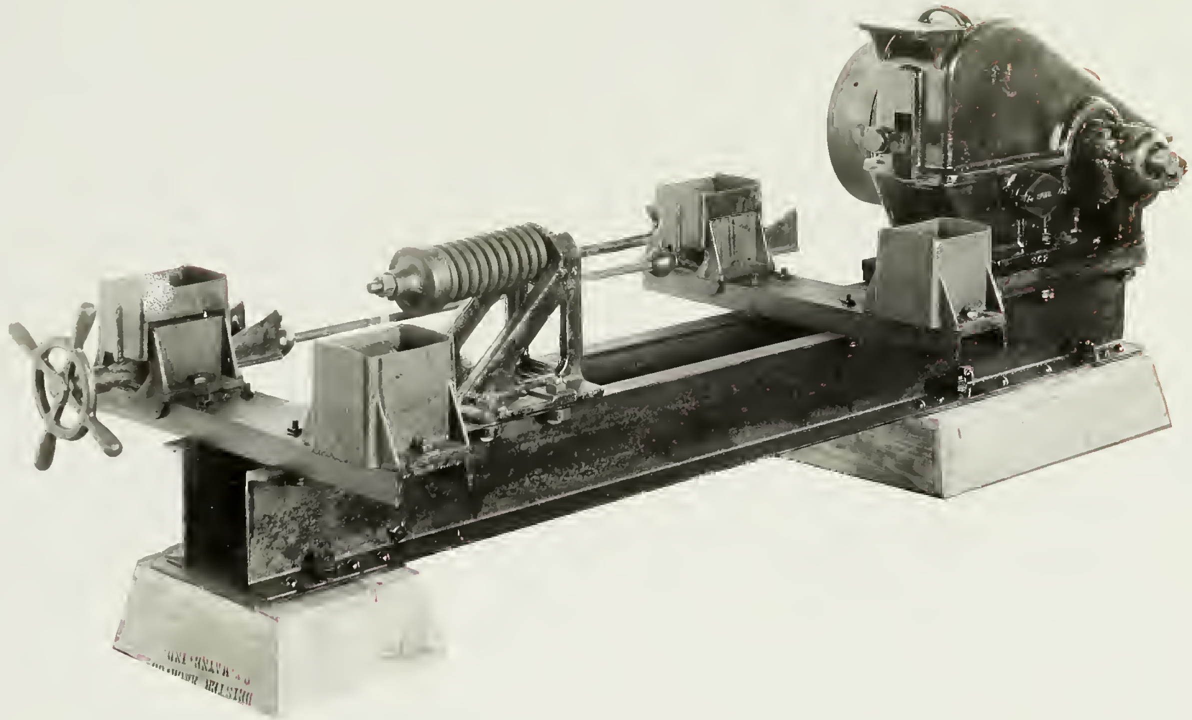


Fig. 12- Underconstruction of the Plato Table

Fig. 13- The Deister-Overstrom Coal Washing Table

mately the shape of a parellelogram, transversely inclined, and reciprocated 230 to 270 times a minute by a head motion mechanism. This deck is supported by means of toggles, or slides, on a tilting frame, which allows the transverse inclination to be readily changed. On the top are tacked wooden cleats, or riffles, which taper vertically from the head motion end, where they have a thickness of about one-half inch, to a feather edge at the "refuse discharge end". The riffles are about one-fourth inch wide set about one and one-fourth inches apart, although this varies somewhat according to the material treated.

Their operation is as follows: The raw coal, previously mixed with about twice its weight of water, is delivered to the feed box in the upper corner at the head motion end of the deck, and thence through a series of small holes onto the deck. Water distributing boards are provided and attached to the same side of the deck as the feed box in order to obtain a nice adjustment in the distribution of water over the deck surface. A slight side inclination at right angles to the line of reciprocation, and which is adjustable in order to meet changing conditions, permits the clean coal to be washed down over the long edge of the table into a trough or launder, while the action of the head motion in reciprocating the deck, drives the sulphur and refuse, which stratify next to the surface of the table deck in accordance with their greater specific gravity, out and over the short edge, or refuse end of the table, where it is caught in launders and conveyed to the refuse dump. The wooden riffles on the surface of the deck aid in the collecting and guiding the refuse to its proper point of discharge from the table, and also prevent the finer particles from washing over with the

clean coal.

The coal washing tables are very similar to the ore tables. The principal changes which were made in order to use them for coal washing being in the riffling, which generally is deeper on the coal washing tables although so many kinds of riffles have been used in experimental work with the various tables that a generalization is uncertain. The Deister-Overstrom table is made larger for coal washing, being seven feet wide by sixteen feet long, as compared with six feet wide by fourteen feet long for the ore table.

The first use of concentrating tables on a commercial scale was at the Stag Canon plant of the Phelps Dodge Corporation at Dawson, New Mexico. A Wilfley sand table was installed there in 1906[1] and used for some time as an experiment, but was abandoned because of its small capacity. In 1911 further experimental work was done with the larger Massco table and an installation of twenty-four tables was made. Since that time practically all the different tables made have been tried there including the Butchart, Plato, Deister-Overstrom and Overstrom-Universal. In 1917 there were fifteen tables of all makes in operation there, mostly Deister-Overstrom, as this table was preferred there at that time because of the high capacity secured by the large diagonal deck. In 1919 an Overstrom-Universal table was installed for experimental purposes and the following results were secured in a test run[2].

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[1]Personal communication from Mr. J. B. Morrow, formerly Supt. Coke Department, Phelps Dodge Corporation, Stag Canon Branch.

[2]Coal Washing with Concentrating Tables, J. B. Morrow, Coal Age, Sept. 25, 1919.

[illegible]

[illegible]

[illegible]

The feed to the table, which consisted of reground middlings from jigs contained, as shown by a sink and float separation at 1.40 specific gravity:

	46 per cent of material	at 48.0 per cent ash
	54 " " " "	" 11.3 " " "
Total feed	100 per cent	at 28.2 per cent ash

The products from the table were

49.0 per cent of	clean coal	at 11.6 per cent ash
40.6 " " "	refuse	at 48.7 " " "
10.4 " " "	middlings	at 27.5 " " "
100.0	Average	27.66

The raw coal handled at this washer is a very difficult one to wash as it consists very largely of boney coal and thin bands of shale and coal interstratified. Mr. Morrow reports that the Overstrom-Universal table gives better results than any table they have used.

Extensive experiments with the Butchart, Deister-Overstrom, and Plato tables have also been made at the Middlefork washer of the United States Fuel Company near Benton, Illinois, but as yet no permanent installation of tables has been made there although it has been thoroughly demonstrated that tables will reduce the sulfur content of the fine coal lower than will the feldspar jigs.

Other plants where concentrating tables have recently been installed are:

	Table Used
Renton Coal Co., Renton, Washington,	Deister-Overstrom
Potter Coal & Coke Co., Coral, Pennsylvania,	Plato
Jamison Coal & Coke Co., Hannastown, Pa.,	Plato
Lackawana Coal & Coke Co., Wehrum, Pa.,	Deister-Overstrom
Duncan Coal Co., Greenville, Ky.,	Plato
Carbon Hill Coal Co., Carbonado, Wash.,	Plato
Carbon Coal & Clay Co., Bayne, Wash.,	Plato
Madeira-Hill Co., Several anthracite breakers in Pennsylvania	Deister-Overstrom

The chief advantage of the concentrating table as a coal washer lies in the fact that the operation is fully visible at all times, is capable of very close adjustment and the separation of the products may be easily made at any point or as many points as desired by simply dividing the sheet of water and coal coming off around the discharging edges of the table.

THE CAMPBELL WASHER

The Campbell washer is a bumping table similar to the Gilpin County bumping table developed in the early days of mining in Colorado for the concentration of gold ores.

Ten of these tables are in use in Illinois at the No. 7 mine of the Big Muddy Coal and Iron Company at Herrin. Fig. 14 is a rough sketch showing the general features of the machines used at this washery. The tables, five feet long by two and one-half feet wide, are made of one inch oak plank on a 4" x 8" oak keel (a) and is supported in such a way that it can reciprocate longitudinally. The bumper pulley (b) is driven at one hundred revolutions per minute giving the table a two and one-half inch stroke with a bump on the back stroke. When the cam (c) passes the keel (a) the spring (d) jerks the table back bumping the keel against the pulley.

The table is inclined slightly toward the washed coal launder. The coal, flushed onto the table, as shown, near the back or refuse discharge end, is carried forward by the flow of water and washed over the end of the table into the washed coal launder. The bed of coal, as it travels down the table, is agitated by the jerking motion and the heavy refuse collects on the bottom lodging behind transverse riffles (e), which are vertical on the back side and slope gently on the front side (toward the washed coal discharge

[illegible]

Fig. 14 - The Campbell Bumping Table as used in Illinois

end).

The bump which the table receives on the return stroke works the refuse back against the inclination of the table so that it is eventually discharged over the back end of the table into a refuse chute between the piers which support the bumping pulley.

The efficient operation of this washer depends upon the adjustment of table slope, volume of water used, length of stroke and tension of the spring to such a condition that the heavy refuse will be worked toward the back of the table by the bump, while the light coal will be carried forward by the flow of water.

Campbell tables are used in America at the following plants[1] for washing coking coal:

Cambria Steel Co. Washery No. 1, Johnstown, Pa., Erected 1905	36-12 ft. tables 200 tons per hour
Cambria Steel Co. Washery No. 2[2], Johnstown, Pa., Erected 1920	36-12 ft. tables 200 tons per hour
Lackawana Coal & Coke Co., Wehrum, Pa., Erected 1905	56-9 ft. tables 235 tons per hour
Dominion Iron & Steel Co., Sydney, N. S. Erected 1905	48-9 ft. tables 200 tons per hour
Cascade Coal & Coke Co., Tyler, Pa., Erected 1906	36-9 ft. tables 150 tons per hour
Vinton Colliery Co., Vintondale, Pa., Erected 1907	24-9 ft. tables 100 tons per hour
Jefferson & Clearfield Coal & Iron Co., Ernest, Pa., Erected 1908	24-9 ft. tables 100 tons per hour

In addition to these plants for washing coking coal a number of

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[1]Personal communication W. E. Winn, Heyl & Patterson, Inc., Pittsburgh, Pennsylvania.

[2]Now under construction.

washeries for preparing coal for fuel are in operation in America. This table is also used in Great Britian where it is called the Craig washer.

20. Classifier Washers. Washers of this type have a continuous rising current of water which is strong enough to carry the coal particles up while the refuse settles against it.

The Robinson washer consists of an inverted steel cone inside of which are vertical arms and stirring plates revolved by gears. The bottom of the cone opens into a cylindrical refuse chamber which is closed above and below by slide valves operated by steam pistons. The rising current of water enters at the bottom of the cone through perforations in the top of an anular ring which surrounds the refuse chamber. The coal to be washed is introduced at the center of the top of the cone. The material in the cone is kept in a continual state of agitation by the stirring arms and the rising water current carries the light coal over the top of the cone, while the heavier refuse particles settle into the refuse chamber, the upper slide valve being kept open and the lower valve closed during washing. When the refuse chamber is about full it is emptied by closing the upper valve momentarily and opening the lower valve. A photograph of a model Robinson washer in the Mining Laboratory of the University of Illinois is shown in Fig. 15. The Robinson wash-

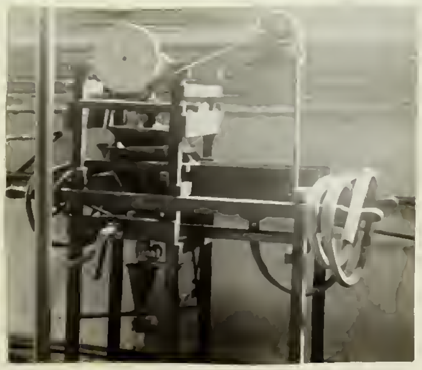

Fig. 15 - Model Robinson Washer.

ers are ten and one-half feet in diameter and ten and one-half feet high with a two foot discharge.[1] The Howe cone washer is similar but shorter in proportion to its diameter and has horizontal instead of vertical stirrers.

The Robinson washers were very widely used in the south at one time, but in the newer washeries have been largely superseded by jigs. The following new installations of cone washers of this type are reported, however, in recent years. At five of the anthracite breakers of the Lehigh Coal and Navigation Company cone washers similar to the Howe are being used to wash No. 4 buckwheat in which the ash content is reduced from 30 to 35 per cent to 17 or 18 per cent. Previous to 1916, when this type of washer was introduced for anthracite preparation, the No. 1 buckwheat was the smallest size of anthracite washed. It is also reported that some experimental work is being done with the Robinson washer at the Stag Canon washery of the Phelps Dodge Corporation.

Another rising current classifier washer which is attracting considerable attention in Great Britain is called the Draper[2] washer. This is essentially a tubular classifier with a short inverted cone in the upper part which serves to constrict the diameter of the classifier and produce a zone of maximum lifting effect which separates the heavier particles of refuse from the coal. Results of experimental work carried cut at the first plant erected at the Glamorgan Colliery Llewellyn are as follows:

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[1]Lincoln, Coal Washing in Illinois, p. 25, Eng. Exp. Sta. Bull. 69.

[2]Coal Washing, Professor George Knox Proc. S. Wales Engineers, Vol. 34, No. 3.

[illegible]

TABLE 7

Results of Tests on the Draper Washer

Material washed	% Ash in raw coal	% Ash in washed coal	% Ash in refuse
Fine coal	31.0	5.7	71.2
" "	22.7	4.1	73.2
Slurry 1/8" to 0 size	23.7	2.2	70.6
" 1/8" " 0 "	13.8	4.25	67.4
" 1/8" " 0 "	30.2	4.8	71.7

Samples of fine coal from a Southern Illinois mine were sent to England in the summer of 1919 for tests with this washer. The results secured were no better than have been secured by jigging samples of the same coal.

21. Cleaning Coal by Oil Flotation. In the past few years some experimental work has been done with a view to the utilization of the flotation process for cleaning fine coal. This process as used for concentrating sulfide ores consists in agitating the finely crushed ore with water and a small percentage of oil, sometimes also with a small percentage of acid and accompanied by aeration. A froth, which floats the ore particles, forms on the surface and is skimmed off. When applied to coal the refuse particles sink and the coal is taken up by the froth. Bacon and Hamor[1] report the results of tests on coal washery refuse conducted by Dr. C. B. Carter at Mellon Institute, Pittsburgh, Pennsylvania. Although successful in making a separation they conclude that this is not an economically feasible process at present, but "it will undoubtedly play a leading

[1]Problems in the utilization of fuels, Journal of the Society of Chemical Industry, June 30, 1919.

role in meeting prominent fuel problems of the future". They succeeded in recovering 70 to 90 per cent of the combustible material in the feed as a fuel of 20 to 25 per cent ash. They report that pyrite floats readily with the coal but that it could probably be controlled by preferential flotation.

Tests on raw coal have been carried out at the Seattle Station of the Bureau of Mines with similar results. The Minerals Separation Company of London, however, has introduced this process of coal washing on a commercial scale, and according to their reports wide plans are being made for its adoption both in Britain and in Continental Europe. At the annual December meeting of Minerals Separation Ltd. Mr. Francis L. Gibbs, chairman, outlined the plans for flotation plants as follows.[1] Waste heaps and current waste from washeries seem to be receiving the most attention. A pilot plant on a commercial scale has been erected at Aberman for experimental work on this material. Three commercial plants for treating such waste are in course of construction and various other accumulations are being examined. A plant for washing coking coal has been contracted for by the Skinningrove Iron Works Company. A one hundred ton pilot plant is under construction at one of the Collieries in France, and plans are being made for plants in Spain, China, Brazil, South Africa, India and Japan.

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[1]The Flotation Process, Colliery Guardian, Dec. 3, 1920.

CHAPTER VI

METHODS USED IN THE EXAMINATION OF WASHERS

22. Standard Methods. In ordinary practice the methods used to determine the character of work being done by a coal washer, consist of, first, the sampling and chemical analysis of the raw coal and the washer products; second, screening tests with analysis of the various sizes; and, third, sink and float tests on samples of the raw coal, washed coal and refuse.

CHEMICAL ANALYSIS

Analysis of the raw coal and the washed coal for ash and sulfur content shows the extent to which the impurities are being removed from the coal by washing. Where the proportions of washed coal and refuse cannot be determined by actual weights, the yield of washed coal secured and the percentage of the original raw coal rejected as refuse are sometimes calculated from the figures for ash content or for sulfur content in these products by solving the following equations:

$$\text{Per cent yield of washed coal} = 100 \times \frac{\text{Refuse ash} - \text{Raw coal ash}}{\text{Refuse ash} - \text{Washed coal ash}}$$

$$\text{Per cent refuse} = 100 \times \frac{\text{Raw coal ash} - \text{Washed coal ash}}{\text{Refuse ash} - \text{Washed coal ash}}$$

These formulae are given by various writers[1] on coal washing.

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[1]Standardization in Coal Washing Reports, Delamater M. & M., March 1912.

[1]Coal Washing, Wendell, Technograph, April 1915.

SCREENING TESTS

Screening tests on the raw coal, washed coal and refuse with chemical analysis of the screened sizes show what size of particles are being cleaned most effectively and what sizes, if any, are not being cleaned. One application of screening tests in locating the source of trouble in an operation where satisfactory results are not being secured is shown in the following table, giving results on a coal which was washed by jigging at 0" - 1" size.

TABLE 8

Screening Tests on Raw and Washed Coal

Size	Raw coal % ash	Washed coal % ash	% Reduction
1" - ½"	12.3	6.8	45
½" - ¼"	12.0	6.4	47
¼" - 1/8"	14.6	7.7	47
1/8" - 20 M	18.3	11.0	39
- 20 Mesh	22.0	20.2	8

These figures show poor work on the fine material below 1/8 inch in size, and practically no reduction in ash in the sluge through a 20 mesh screen. It would probably be advantageous in this case to screen the raw coal into two sizes ¼" - 1" and 0 - ¼" and wash each size separately, or to screen the washed coal and rewash the material which passes through a ¼ inch screen.

SINK AND FLOAT TESTS

Sink and float tests on the washer products are ordinarily made in order to determine the amount of float material or coal being discharged with the refuse and the proportion of refuse retained in the washed coal. In as much as the separation of coal from ref-

use by washing depends entirely upon their difference in specific gravity, the sink and float test is the ideal method of checking the work of the washery. Such a test when very carefully made gives a practically complete separation at the specific gravity of the solution used; and comparison of these results with the results secured by washing gives a measure of the effectiveness of the washing operation. Having determined by a specific gravity analysis, as described and illustrated in the chapter on "Principles of Coal Washing", the specific gravity of the solution which makes the right separation to produce the maximum yield of washed coal of the required degree of purity: solution of that specific gravity is then used to determine the proportion of sink left in the washed coal and the amount of float coal left in the refuse.

A machine which is now widely used for making these tests was developed by Mr. G. R. Delamater[1] while operating the U. S. G. S. fuel testing plant at Denver, Colorado. This machine, called the Delamater Standard Sink and Float Machine, is illustrated in the photograph, Fig. 16. It consists essentially of a rectangular cast iron tank with rounded ends. A strap iron frame, which may be raised or lowered in this tank by means of a rack and pinion device, holds two ten inch brass testing sieves side by side in a horizontal position. A ten inch open cylinder, which will fit inside the testing sieves, is supported on a track in the upper part of the tank so that the cylinder can be slid along from one end of the tank to another just clearing the sieves when they are in the lowest position at the bottom of the tank.

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[1]Mines and Minerals, August, 1909.

Fig. 16- The Delamater Standard Sink
and Float Machine

To make a sink and float test the tank is filled with a solution of the desired specific gravity and the sieve frame carrying the sieves is clamped in an intermediate position so that the cylinder rests in one of them forming a continuous cylindrical vessel with a screen bottom. The sample to be tested is placed in this vessel and agitated to thoroughly wet all the particles and disengage them from each other. It is then allowed to stand quiet for a time to allow the heavy particles to sink into the sieve and the float particles to collect on top of the solution in the cylinder. The sieves are then lowered to the bottom of the tank; the cylinder with the float particles which are in it is carefully moved over to a position above the empty sieve and the sieve frame is raised to the surface, bringing the sink in one sieve and the float in the other. The two products are rinsed thoroughly with water to remove the salt which was used in the solution then dried, weighed and sampled. In this study the Delamater machine was used for making tests on coarse coal of jigging size.

In working with small coal, such as some washeries are now handling, through a ¼" screen, or through a 1/8" screen with a large proportion of slime, a need has arisen for an apparatus in which all the solution used, as well as the coal sample, is divided into a float portion and a sink portion and each screened or filtered with the respective float and sink portions of the coal sample.

The machine illustrated in Fig. 17 was designed for this purpose. The apparatus assembled ready for use is shown in Fig. 17. The three separate pieces which make up the apparatus are shown in Fig. 18 and details of construction of the barrel are shown in Fig. 19. The machine was made in the laboratory shop, of a three inch

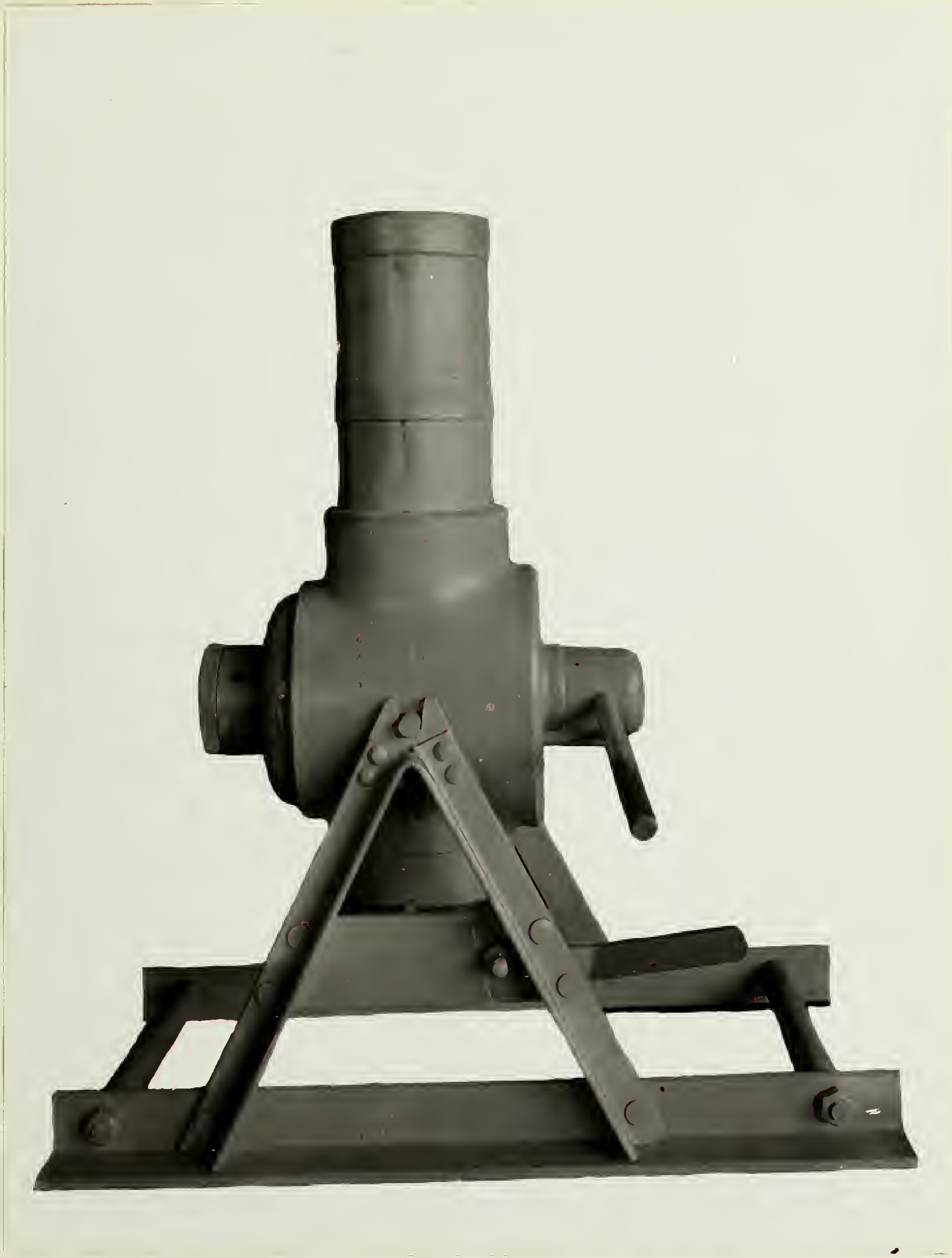

Fig. 17 - The New Sink and Float Machine

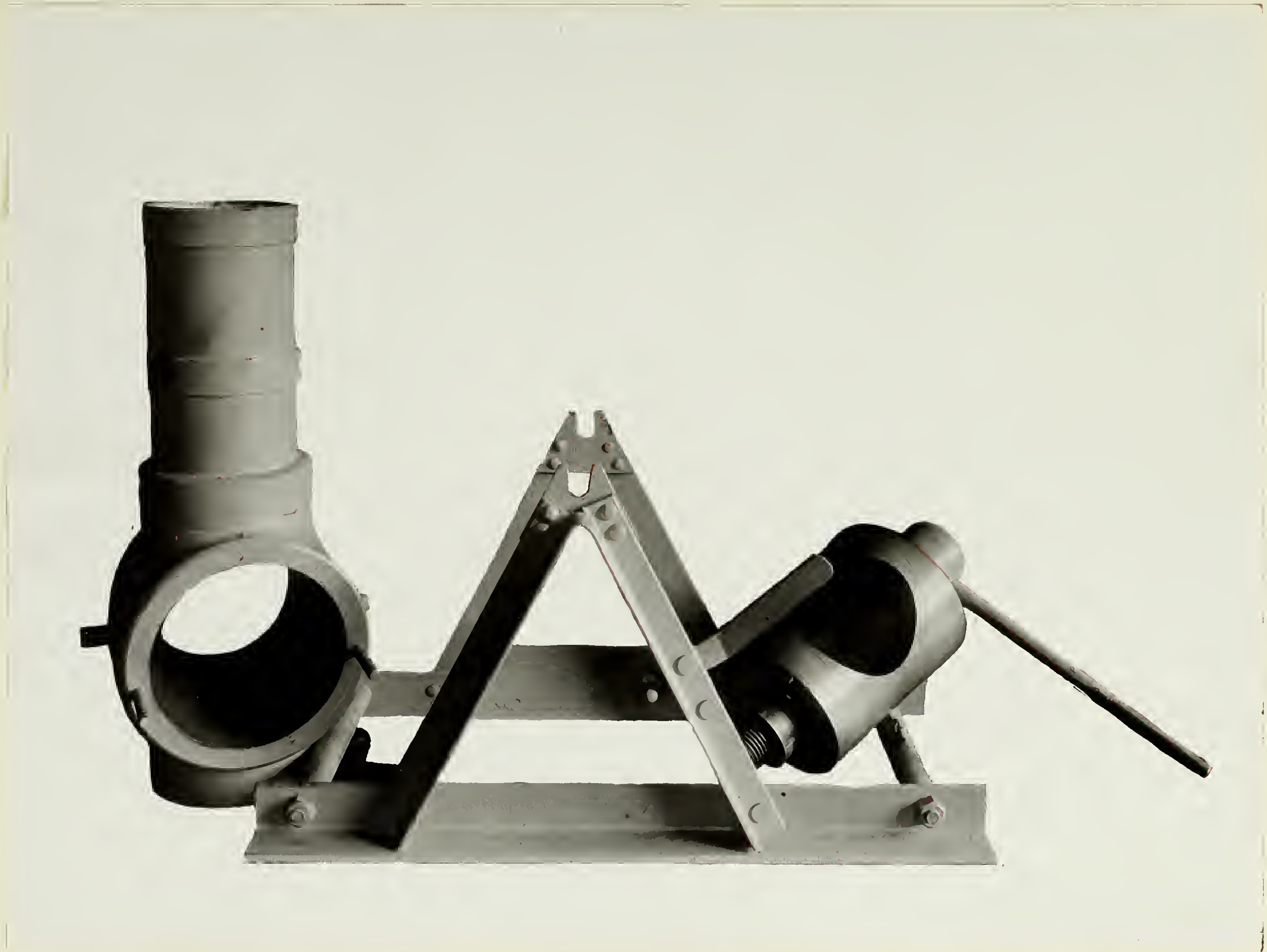

Fig. 18- New Sink and Float Machine dissembled showing Parts

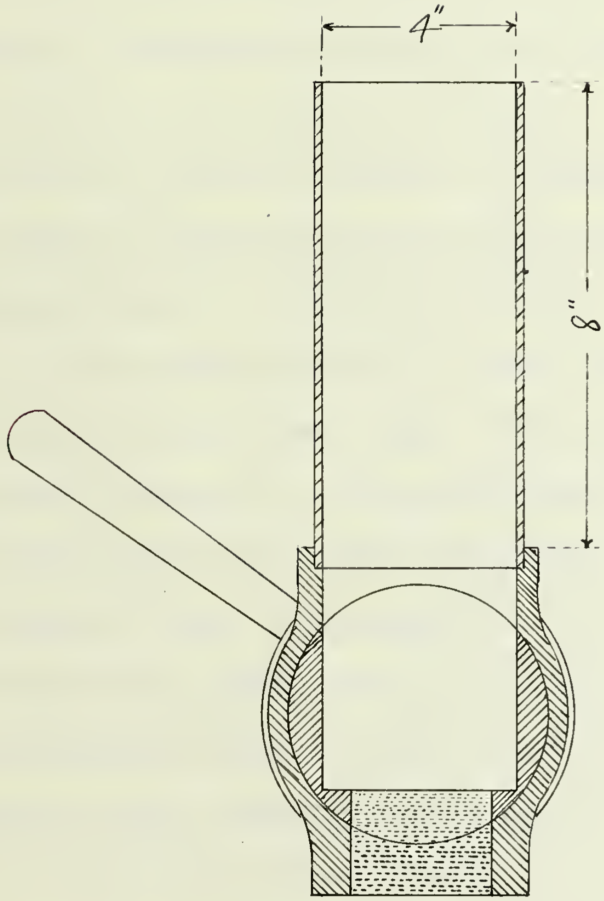

Fig. 19 — Details of Barrel of New Sink and Float Machine

roundway stopcock valve, a piece of four inch galvanized pipe and tilting frame. It is so simple in construction and operation that very little description is necessary.

The bore of the valve plug was cut out to four inch size at one end and almost through to the other side of the plug. This small end of the bore was then filled with babbit so that the valve plug instead of a three inch round hole through it has a four inch cylindrical well in it as shown in Fig. 19. In the valve body one opening was cut out to four inches in diameter and a galvanized pipe ten inches long and four inches in inside diameter was soldered on. The opposite opening was closed with babbit. The four inch galvanized pipe and the four inch well in the valve plug form the container for the sink and float bath. For convenience in manipulation this barrel was pivoted on a tilting frame fitted with a catch at the bottom for holding the barrel rigid when in the vertical position and a stop for the valve handle to facilitate lining up the well in the valve plug with the bore of the galvanized pipe.

In making a sink and float test the valve handle is turned over against the stop forming a continuous cylinder of the pipe and valve which is filled to within about two inches of the top with a solution of the desired specific gravity. The coal sample is then immersed in the solution and stirred till thoroughly wetted. It is then allowed to stand undisturbed for a short time to permit the heavy particles to sink to the bottom and the light particles to rise to the top. The valve handle is then turned through 180 degrees, care being used to avoid jerking or jarring the machine. This separates the heavy particles in the well of the valve plug from the light particles floating in the upper part of the galva-

nized cylinder.

By tilting the barrel of the machine the float coal and solution is then poured out into a fine screen or a filter, the solution is drained off for use in another determination and the adhering particles of float coal in the machine are flushed out on the filter with a small stream of water. The valve is then turned back to the open position and the sink coal and solution is poured onto another screen or filter in the same manner. The products are then washed with water on the screens or filters to remove all trace of the solution used. By using this apparatus with filters for washing the products all the sample is recovered and there is no loss of fines by suspension in the solution. The small volume of solution used makes the operation with a vacuum filter fairly short. On samples from which the slime has been removed a 100 mesh screen is used instead of the filter. This machine was designed to make the separation just above the top of the sink in the cylinder so that practically all of the solution carrying particles in suspension goes with the float. The float, therefore, includes particles of the same density as the solution and lighter.

In the literature on the subject of coal washing the statement is often found that the sink and float test gives a 100 per cent perfect separation. This means on the basis of the specific gravities of the particles in the sample as they are at the instand when the separation is made between sink and float in the solution. A number of tests in which the float coal from five pound samples was retested immediately after the first separation showed from one to three sink particles in the float. The coal tested was an Illinois coal at ¼" - ½" size in which the average proportion of

sink was 12 per cent. In retesting the float it was reimmersed in the same solution immediately after the first separation and allowed to remain only ten seconds in order to avoid as far as possible increase in specific gravities of the material by absorption of water. These tests show that the separation between heavy and light particles as they exist at the moment the separation is made is practically 100 per cent complete if the test is made carefully.

There are, however, a number of conditions which affect to a considerable degree the results secured by sink and float tests. The most important of these conditions are probably the moisture content of the sample when tested, the length of time of immersion of the sample in the solution and the thickness of the layer of raw coal formed by the sample when placed in the vessel in which the test is made.

Several extensive studies have been made on the subject of specific gravity of coal. At the U. S. Geological Survey fuel testing plant[1], which was operated in St. Louis in 1904, specific gravity determinations were made on eighty-two samples of central district coals. The average value obtained for clean coal was 1.29 and for average raw coal 1.34.

Nebel[2] made an extensive investigation of Illinois coals determining the specific gravity of samples under different conditions as regards moisture content.

Ordinarily two figures are given for the specific gravity of a coal, one designated the "apparent" specific gravity and the

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[1]U. S. Geol. Survey Bull. 323.

[2]Specific Gravity Studies of Illinois Coals, Eng. Exp. Sta. Bull. 89.

other the "true" specific gravity. The apparent specific gravity is the specific gravity of the coal including the moisture or air contained in its pores. The true or "real" specific gravity is the specific gravity of the actual coal substance corrected for air and moisture content. In determining this value the weight of the moisture ~~per cent~~ is deducted from the weight of the coal and all air is removed from the pores of the coal by boiling before it is weighed in water.

In coal washing it is the "apparent" specific gravities of the individual particles as units including impurities, pore space and whatever is in the pores at the time the coal is fed to the washer which is effective in bringing about a separation. For this reason, from the practical point of view, the "true" specific gravity does not enter into the problem of coal washing.

Nebel made specific gravity determinations on freshly mined coal containing the natural vein moisture and on samples of air-dry coal after immersion in water for varying periods of time. His work led to the conclusion that the coal in place in the bed is saturated with water, and that air-dry coal immersed in water increases rapidly in apparent specific gravity during the first hour. This shows that in making a sink and float test the effective specific gravity of the material will increase gradually from the instand the sample is immersed in the solution and particles will be continually leaving the float and joining the sink. Nebel's tests showed increases of from 0.02 to 0.03 in specific gravity during the first five minutes of immersion in water.

More recently T. J. Drakeley[1] determined the effect of drying under various conditions on the specific gravity of lumps of coal. Samples of wet freshly mined coal continued to lose weight for 586 hours when exposed to the air. After this time the specific gravity varied with the hygrometric state of the atmosphere. The maximum variation in the air-dry sample being from 1.2008 in a steam heated laboratory to 1.2261 during a period of wet weather when heating of the laboratory was suspended.

The size and shape of the vessel in which the sink and float test is made will also affect in a measure the results attained. It is apparent that two duplicate samples of the same size, one of which is tested in a tall narrow vessel, and the other in a wide shallow vessel, will not give identical results. More time will be required for the separation to be completed in the tall vessel and on the other hand, more difficulty will be experienced in removing separately the sink and the float products from the shallow vessel. The important point in this connection is to make the maximum size of sample treated small enough in proportion to the size of the vessel. The thicker the layer of raw coal in the solution when tested the more chances will there be for light particles of sink to be enclosed in and carried up by the mass of float particles and vice versa.

These investigations show the necessity of standardizing the conditions as regards moisture content of sample, time of immersion and apparatus used in making sink and float tests.

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[1]Coal Washing, Further Scientific Studies, Colliery Guardian, March 12, 1920.

These are conditions which can only be fixed arbitrarily as there is no one naturally correct method of procedure. For these reasons the sink and float test is a method of analysis which must be carried out very carefully in order to be of any real value, moreover it is a method which is easily misused to misrepresent the facts about the operation of a machine, as it is possible to secure most any result desired. Therefore it is just as essential to know the conditions under which a sink and float test was carried out as to know the results.

At practically all commercial washeries the raw coal after crushing goes through raw coal storage bins which hold several hours or perhaps several days output of the plant. The coal when it is fed to the washer, therefore, is usually in a more or less air-dry condition. Largely for this reason the air-dry condition was adopted as standard for samples for the sink and float tests in this study. The time of immersion was fixed at sixty seconds after and not inclusive of the time used for stirring the sample in the solution to thoroughly wet it. This is sufficient time to allow the sink and float particles to come to their respective positions and yet sufficiently short to minimize the effect of absorption of solution by the coal particles. In tests carried out in large glass cylinders the solution intervening between the float product and the sink product appeared to have come to approximately a state of equilibrium after sixty seconds, although there is always some movement of particles of intermediate density in this part of the solution.

In the Delamater apparatus which was used for tests on samples of coal coarser than one-fourth inch in size, the maximum

size of sample treated was 2500 grams. In the cylindrical machine used for fine coal up to 3/8" maximum size, the largest samples treated were 400 grams. In each case this gives a maximum thickness of coal in the vessel of three inches.

The important thing in making a series of sink and float tests in the examination of a washery is to fix upon a definite standard set of conditions and maintain them consistently throughout in order that the results may be comparable.

SAMPLING FOR SINK AND FLOAT WORK

The sampling of coal for a sink and float test is more difficult than sampling for chemical analysis, because the coal as tested must be at the size at which it is washed and cannot be crushed before quartering as in sampling for analysis. Larger samples must therefore be taken and they must be handled as little as is consistent with accuracy in order to avoid breakage, which by disengaging refuse from coal affects the results of the test.

Blythe and O'Shea[1] in an investigation of coal washing in the British fields made sink and float tests on a number of duplicate samples in order to determine how large a sample must be taken to give accurate results. They also made tests with colored counters mixed together in various proportions and came to the conclusion that a minimum of two thousand particles is necessary in order to keep the mean probable error within 0.5 per cent. On this basis the minimum weight for various sizes of coal is about as follows:

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[1]The Examination of Coal in Relation to Washing, Trans. Inst. Min. Eng., LVII, p. 261.

Size inches	Weight grams
- 1/10	10
1/16 - 1/8	50
1/8 - 1/4	200
1/4 - ½	1000
Over ½	20,000

These investigators apparently did not give due considerations to the difference in the nature of various coals as it would appear that the accuracy of sampling would depend more upon the net amount of the smallest constituent, that is, on the weight of sink in the sample, assuming that the sink is the smaller product, than upon the gross weight of the total sample taken. For example, if the total amount of raw coal to be sampled, contains only one particle of sink, no sample less than the entire lot would be perfectly representative; on the other hand, if the raw coal were approximately half sink and half float and were perfectly mixed, a sample consisting of only a few pieces would be representative. From theoretical considerations it appears that the minimum size of sample which can be used depends upon the necessity for compensating errors due to imperfect mixing of the sample and on the proportion of the smallest constituent being determined.

On all the coals used in this study, preliminary sink and float tests were made on duplicate samples, taken in the usual manner, in order to determine the variation from the average in determinations on samples of the size used. In addition to this precaution, in 1919 a general investigation of this subject was made using a coal from the Sharon Mine in the Danville district in Illinois and one from Ramage, West Virginia. The Sharon coal was a high ash screening containing a comparatively large percentage of free dirt, such as is used at the University of Illinois power plant and the

[illegible]

Ramage coal was a high sulfur, low ash coal in which the impurities were largely disseminated through the coal in fine particles. These were, therefore, two radically different types of coal. Results of the sink and float tests, Tables 9 and 10, give a further indication of the amount of impurity in the coal samples used.

Samples of each of the two coals as received at the laboratory amounted to over two thousand pounds. The West Virginia coal was sampled at 0" - 2" size by the alternate shovel method taking every fifth shovel. This sample of about four hundred pounds was then crushed to ¼" size and divided into sixteen approximately equal parts by dividing and redividing in the usual manner with the Jones riffle sampler.[1] Each of these sixteen parts was then reduced to about one hundred grams size by the same process. These samples were used for the check sink and float tests. The Sharon coal was sampled in the same manner except that it was divided in half and one-half was crushed at once to one-fourth inch maximum sized and used for the sampling. Results of these tests are given in Tables 9 and 10 and are shown graphically in Fig. 20 where the per cent float is plotted against weight of sample and weight of sink portion of sample. This gives the data in the form of a probability curve. The figures plotted for the larger samples are averages of two or more of the unit samples on which actual determinations were made.

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[1]Chemical Study of Illinois Coals, S. W. Parr, Illinois Coal Mining Investigations, Bull. 3.

TABLE 9

Sink and Float Tests on Duplicate Samples of a West Virginia Coal 0" - ¼" Size

Weight of sample grams	Weight of sink grams	Per cent sink
97	7.8	8.0
111	10.1	9.1
118	10.0	8.5
114	9.1	7.9
86	7.5	8.7
105	9.2	8.8
175	19.3	10.7
110	9.5	8.6
201	12.0	6.0
Probable mean error............................		.27
Probable individual error......................		.83

TABLE 10

Duplicate Sink and Float Tests on Sharon Coal 0" - ¼" Size

Weight of sample grams	Weight of sink grams	Per cent sink
47.4	17.6	37.2
56.4	21.1	37.4
58.2	23.2	39.8
71.8	29.4	40.1
86.5	33.9	37.2
74.0	30.2	40.7
60.7	24.0	40.0
76.1	30.1	39.4
108.5	40.4	37.4
82.0	30.1	36.7
116.9	43.8	37.5
102.0	38.9	38.0
61.0	22.6	37.3
77.0	28.3	36.9
82.0	31.2	37.7
Probable mean error..........................		.06
Probable individual error....................		.56

From these tests it was concluded that for a coal containing a large percentage of free dirt, like the Sharon coal, a sample of

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]

[illegible]

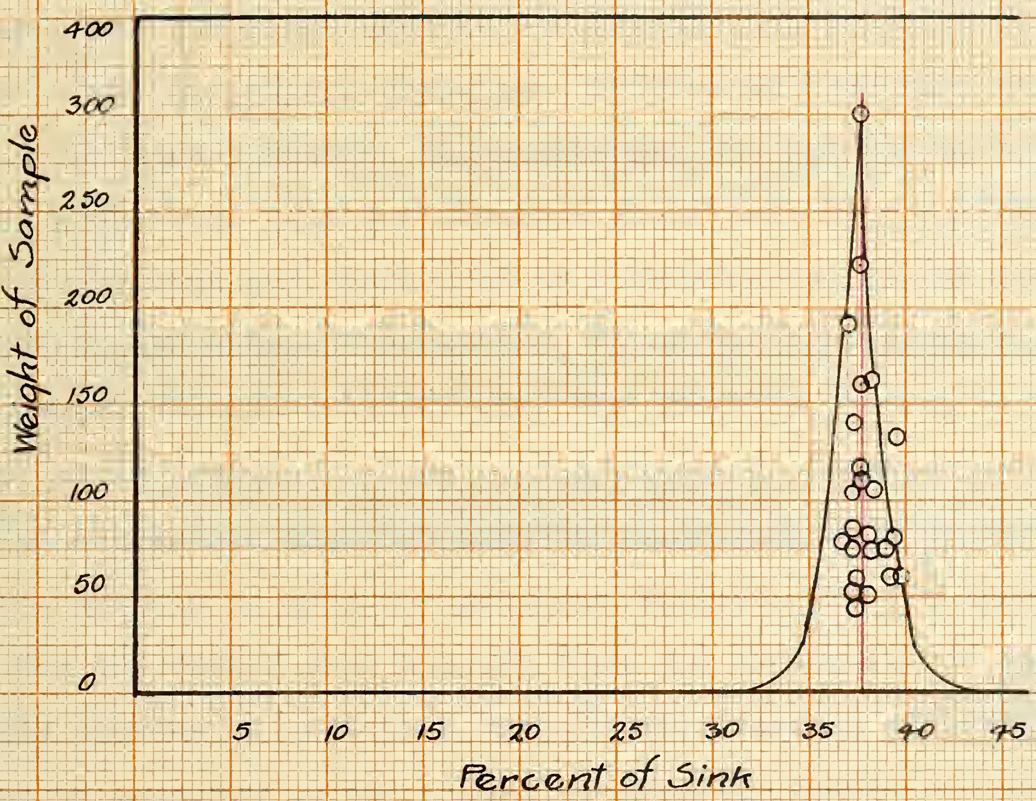

Fig. 20 — Curves Showing Variation from the Mean in Duplicate Sink and Float Tests

200 grams, as recommended by Blythe and O'Shea, would be sufficient for the 0" - ¼" size, but for the other type of coal, where the present sink is very small, a much larger sample is necessary. Four hundred grams was fixed upon as the minimum for coals of this kind.

23. Efficiency Formulae. Several methods have been proposed by different writers for estimating the efficiency of a coal washing operation. All the formulae which have been published are based on the sink and float test or a combination of the sink and float test with chemical analysis. Since the separation made in coal washing depends entirely upon the specific gravity of the particles, it is logical to take as the standard of comparison the results of a complete specific gravity separation made at the right specific gravity to give the products desired. If the specifications for the washed coal require that the separation be made at a specific gravity of 1.40 then the effectiveness of the washing operation is measured by the extent to which it approaches perfect separation at this point, discharging as refuse all particles higher than 1.40 in specific gravity and as washed coal all particles which are lighter than 1.40 in specific gravity.

LINCOLN'S FORMULA

F. C. Lincoln[1] calculated the efficiency of coal washeries by the following formula:

$$\text{Efficiency} = \frac{\%\ \text{float in washed coal} + \%\ \text{sink in refuse}}{2}$$

This formula, as explained by its author, is useful for purposes of

[1]Coal Washing in Illinois, Ill. Eng. Exp. Sta. Bull. 69, p. 57.

comparison. That it does not, however, accurately express the mechanical efficiency of the operation is shown by calculation of the efficiency in a case where no separation of refuse from coal is made, and the efficiency is therefore known to be zero. In this case the products designated as washed coal and as refuse would each contain the same proportions of float and of sink as the original raw coal, say for example 85 per cent float and 15 per cent sink. The efficiency as calculated would be

$$\frac{80 + 15}{2} = 50 \text{ per cent}$$

DELAMATER'S FORMULAE

In 1914 G. R. Delamater[1] proposed a set of four formulae for calculating coal washing efficiencies under four different sets of conditions. Having determined, by subjecting samples of the raw coal to sink and float tests on solutions of various specific gravities, the solution which makes the most desirable separation; the float on this solution, called the "permissible bath", is designated as standard washed coal and the amount of this float product as a percentage of the raw coal sample is taken as the standard yield of washed coal. The efficiency of a washing operation is then calculated as follows:

Condition (1) where the yield of washed coal is standard and the ash content of the washed coal is above the standard.

$$\text{Efficiency} = \frac{\text{Raw coal ash - Washed coal ash}}{\text{Raw coal ash - Standard washed coal ash}}$$

Condition (2) where both the yield of washed coal

[1]Coal Washing Efficiency Calculations, Coal Age, May 2,1914.

and its ash content are above the standard.[1]

Condition (3) where the yield of washed coal is below the standard and its ash content is standard.[1]

Condition (4) where both the yield of washed coal and its ash content are below the standard.[1]

Apparently these formulae are based on an idea of two efficiency factors, a yield efficiency expressing the relation of actual yield to the hypothetical yield corresponding to perfect separation and an ash removal efficiency representing the ratio of actual ash reduction to that secured by perfect separation.

The numerical average of these two efficiencies is designated as the general efficiency except in condition (1) which in order to make it consistent with the other three formulae should be changed to

$$\text{Efficiency} = \frac{100 + \dfrac{\text{Raw coal ash - Washed coal ash}}{\text{Raw coal ash - Standard washed coal ash}}}{2}$$

While these formulae are valuable for the comparison of two or more operations all of which come under the same one of the above four conditions; efficiency values calculated by the different formulae are not directly comparable with each other, because the physical significance of the relations expressed between the different factors differs in the various formulae. In condition (2) the yield efficiency is expressed by the following relation between

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[1]The formulae are shown on the following page.

Condition (2)

$$\text{Efficiency} = \frac{\dfrac{\text{Washed coal yield} - \text{Standard washed coal yield}}{100 - \text{Standard washed coal yield}} + \dfrac{\text{Raw coal ash} - \text{Washed coal ash}}{\text{Raw coal ash} - \text{Standard washed coal ash}}}{2}$$

Condition (3)

$$\text{Efficiency} = 100 + \frac{\dfrac{\text{Washed coal yield}}{\text{Standard washed coal yield}}}{2}$$

Condition (4)

$$\text{Efficiency} = \frac{\dfrac{\text{Washed coal ash}}{\text{Standard washed coal ash}} + \dfrac{\text{Washed coal yield}}{\text{Standard washed coal yield}}}{2}$$

actual yield and the standard yield.

$$\frac{\text{Washed coal yield} - \text{Standard washed coal yield}}{100 - \text{Standard washed coal yield}}$$

While the corresponding part of formula (4) is expressed as the direct ratio of actual yield to standard yield.

$$\frac{\text{Washed coal yield}}{\text{Standard washed coal yield}}$$

That these two expressions have an altogether different significance and will, therefore, give values which are not comparable is obvious.

DRAKELY'S METHOD

T. J. Drakely[1] has recently suggested a method of calculating the efficiency of washing, which is based entirely on sink and float results. Like Delamater's equations it consists of two factors which in this case are designated qualitative efficiency and quantitative efficiency.

$$\text{Qualitative efficiency} = \frac{\text{Washed coal float} - \text{Raw coal float}}{100 - \text{Raw coal float}}$$

[1]Coal Washing, A Scientific Study, Trans. Inst. Min. Eng., Vol. 54.

Quantitative efficiency =

$$\frac{\text{Raw coal float} - (\text{Refuse float x percentage of refuse})}{\text{Raw coal float}}$$

The general efficiency is the product of the qualitative and the quantitative efficiencies. The author explains the application of his formulae as follows:

TABLE 11

Average Working of Jig Washers

	Raw coal Per cent	Washed coal Per cent	Refuse Per cent
Float	70.25	89.41	2.89
Sink	29.75	10.59	97.11
Output	- - -	78.8	21.20

"From Table 11, which gives the average values for the working of jig washers, it is observed that the concentration of the float particles in the coal is raised from 70.25 to 89.41 per cent. Hence the quality of the coal is enriched by 19.16 per cent out of a possible 29.75 per cent. The qualitative efficiency (19.16 ÷ 29.75) x 100 = 64.4 per cent.

Quantitative Efficiency. Of the total raw material, 21.2 per cent is lost as refuse, and of this 2.89 per cent is coal. Hence coal amounting to (2.89 x 21.2) ÷ 100 = 0.61 per cent of the total output is lost coal. Therefore, the amount recovered is (70.25 - 0.61), or 69.64 per cent out of a possible 70.25. The quantitative efficiency (69.64 ÷ 70.25) x 100 = 99.13 per cent.

I favour the calculation being made as suggested for the

following reason: During the process of washing, a certain amount of slime is invariably produced. This slime is usually, at the present time, a waste product; but future investigation may demonstrate that it is utilisable. In such circumstances, the only loss in the washing process will then be the coal in the refuse. The slime question is not settled one way or the other, and until it is it would appear to be more satisfactory not to regard the slime as being a total loss. If no slime were produced in the washing, the two calculations would become identical.

<u>General Efficiency of the Washing Process.</u> It has been shown above that the process recovers 99.13 per cent of the real coal as washed coal, with the quality improved by 64.40 per cent. Hence the general efficiency $(99.13 \times 64.40) \div 100 = 63.84$ per cent."

This method has the great advantage that it consists of one general formula which is applicable to all cases and may therefore be used for the comparison of washers operating under widely different conditions although the practical utility of such a comparison is a matter of conjecture.

The only weak point in this formula is that it makes no distinction between the heaviest sink particles of pure refuse and the light particles of bone which barely exceed 1.35 in specific gravity. In actual washing practice the heaviest refuse particles are practically all removed early in the operation and such sink material as remains in the washed coal will consist mainly of particles of intermediate density which have been described in Chapter III as natural middling. For this reason the figure for qualitative efficiency calculated by the above formula may be misleading espe-

cially in considering a coal containing a large proportion of material of intermediate density say 1.35 to 1.40. A large part of this will go into the washed coal and the effect on the efficiency value as calculated will be out of all proportion to its effect in increasing the ash content of the washed coal. Of two washers each producing washed coal containing 10 per cent sink in solution of 1.35 specific gravity, in one of which this sink is most all heavier than 1.80 and contains 60 per cent ash and in the other lighter than 1.40 with 20 per cent ash. The first is certainly operating less efficiently than the second.

Any of these formulae are of value for the comparison of results secured with the same or very similar coals on different machines or by different processes, where the conditions of mining, crushing, storing, etc., are the same or they may be of value for comparing results secured with different coals on the same machine to determine the relative washability of the different coals; but for universal application in different operations, where so many variables enter in, the value of such calculations for purposes of comparison are doubtful.

The variety of formulae advanced and the variety of resulting figures secured indicates the great difficulty of arriving at a single figure which accurately expresses the true efficiency of a coal washing operation.

24. Methods Used In the Study. This work has consisted largely of a study of the results securable by washing coals with jigs and with concentrating tables. Investigations were conducted in the field at operating washeries and experimental plants and more intensive studies of the operation of individual machines were

made in the laboratory of the Department of Mining Engineering of the University of Illinois.

The use of efficiency calculations has been limited to the comparison of washing tests with different machines on samples of the same coal or tests with the same coal under different conditions as regards sizing, or for comparing the results with different coals on the same type of machine. For use in the field for estimating the effectiveness of operating washers a method was devised which combines some features of the Delamater formulae with some features of the Drakely formula.

Having ascertained the maximum allowable ash in the washed coal or the limiting sulphur content, if sulphur is the limiting feature, this is designated as standard washed coal and the yield of float coal of the desired degree of purity, determined by a specific gravity analysis of the raw coal is taken as the standard yield of washed coal. The effectiveness of the operation is then expressed by the following:

$$\text{Yield efficiency or quantitative efficiency} = \frac{\text{Actual yield}}{\text{Standard yield}}$$

$$\text{Qualitative efficiency} = \frac{\text{Actual ash reduction}}{\text{Standard ash reduction}} =$$

$$\frac{\text{Raw coal ash} - \text{Washed coal ash}}{\text{Raw coal ash} - \text{Standard washed coal ash}}$$

These two factors are combined as a product in order to reduce the efficiency to a single figure. The qualitative efficiency is based on ash reduction rather than reduction in per cent sink as in the Drakely formula in order to avoid the error due to difference in

impurity of light and heavy particles of refuse. Since the ash content in different particles of any given coal varies directly with the specific gravity, this method of computing qualitative efficiency will give approximately the same figure as would be secured by the Drakely method if a complete specific gravity analysis were made on each product and compensated values computed for the increments of different densities in the refuse retained in the washed coal. To apply the Drakely formula in this manner would be laborious in the extreme, and its use in commercial practice would be impracticable for that reason. Use of the ash reduction for this purpose, however, makes the desired adjustment automatically.

The standard yield is determined by the sink and float method because no other method is available for fixing this point. This requires a complete specific gravity analysis of the raw coal only.

The two factors, yield efficiency and qualitative efficiency, are combined by taking their product rather than their numerical average because each of these factors affects the value of the operation independently of the other; that is, if the ash reduction approaches zero, although the yield may be up to the standard the efficiency of the operation approaches zero. On the other hand, if the yield is zero the efficiency of the operation is zero, although the ash reduction in an infinitesimal portion of washed coal might be standard. In either of these cases, if the numerical average of the yield efficiency and the qualitative efficiency is taken, the Lincoln or the Delamater formula will show an efficiency of 50 per cent, while when the two factors are combined as a product the efficiency in these cases is shown correctly as zero. This

means that the scale of efficiencies runs from 0 to 100 while when the general efficiency is taken as the average of the yield efficiency and the qualitative efficiency it runs from 50 to 100.

In the experimental washing tests which were conducted in the laboratory where equipment and time were available for making a complete study of the operations, specific gravity analyses were made on samples of the raw coal, washed coal, refuse, and in some cases of intermediate or middling products. Screening tests on all the products of the specific gravity analyses then completed the data to show exactly what disposition was made by the washer of each type of raw coal particles as regards density and size, which are the two most important factors affecting the separation of refuse particles from coal particles.

CHAPTER VII

COAL WASHING TESTS

25. Outline of the Experimental Work. It was not the intention in this study to go into the principles of the hydroseparation of minerals with an investigation of settling ratios, rates of falling in water, etc., as that ground has probably been as thoroughly covered as the needs of actual commercial practice justify. The object was rather to examine a number of typical coals, particularly coals which have been found difficult to wash, to determine to what extent these coals can be improved by washing and to determine, if possible, what are the characteristics of the non-washable coals which make them difficult to wash.

Washing tests with jigs and tables were made in the laboratory on samples of coal from the Illinois No. 6 seam at Herrin, from the Bon Air seam at Bon Air, Tennessee, from Beds "C" and "D" in Clearfield County, Pennsylvania, from the Eagle seam of the Kanawha group at Ramage, West Virginia, and from the Indiana No. 3 seam at Terre Haute. Of these five coals the Tennessee coal and the West Virginia coal are classed as distinctly non-washable and the Pennsylvania coal as difficult to wash at jigging sizes.

26. Equipment Used in Experimental Work. The coal washing jigs installed in the Mining Laboratory of the University of Illinois are a Stewart jig with a 8' x 1½' pan, a three compartment New Century (Elmore) jig with the differential eccentric, which gives a rapid down stroke and a slow upstroke to the piston, and a two compartment Hartz jig similar to the Luhrig nut coal jig illustrated in Fig. 8. This jig, shown in the photograph, Fig. 22, was used

Fig. 22 - Experimental Hartz Jig
Used in the Tests

for all the laboratory jig washing tests of this study. The pistons are actuated by simple eccentrics which give equal up and down strokes. The length of stroke and number of strokes per minute are adjustable. The height of the final washed coal overflow gate and of the overflow from the first compartment to the second compartment are adjustable, so that the thickness of the bed of coal maintained on the screens may be varied by the operator. The refuse discharge gate is of the pot valve type consisting of an opening in the discharge side of the jig box just above the screen. Inside the jig box a vertical half cylinder, which covers this opening, extends down through the coal layer of the bed and into the upper part of the refuse layer. The refuse passes under the lower edge of this cylinder and out the gate, but the coal cannot work down through the heavy refuse to enter the cylinder from below. The height of this cylinder is adjustable so that the thickness of the refuse bed may be varied. The rate of discharge of refuse from the jig is regulated by hand by varying the size of the discharge opening. Each compartment, 7" x 15" in screen size, is provided with one refuse discharge valve. A feldspar bed may be used in either or both compartments. The raw coal is fed to the jig by shoveling into a chute from which it runs by gravity into the first compartment of the jig through an adjustable gate, by which the rate of feed may be regulated.

The table washing tests of this study were made on two experimental concentrating tables in the Mining Laboratory of the University of Illinois and on a commercial size coal washing table at the Testing Plant of the Deister Concentrator Company at Fort Wayne, Indiana. The two laboratory tables are shown in the photo-

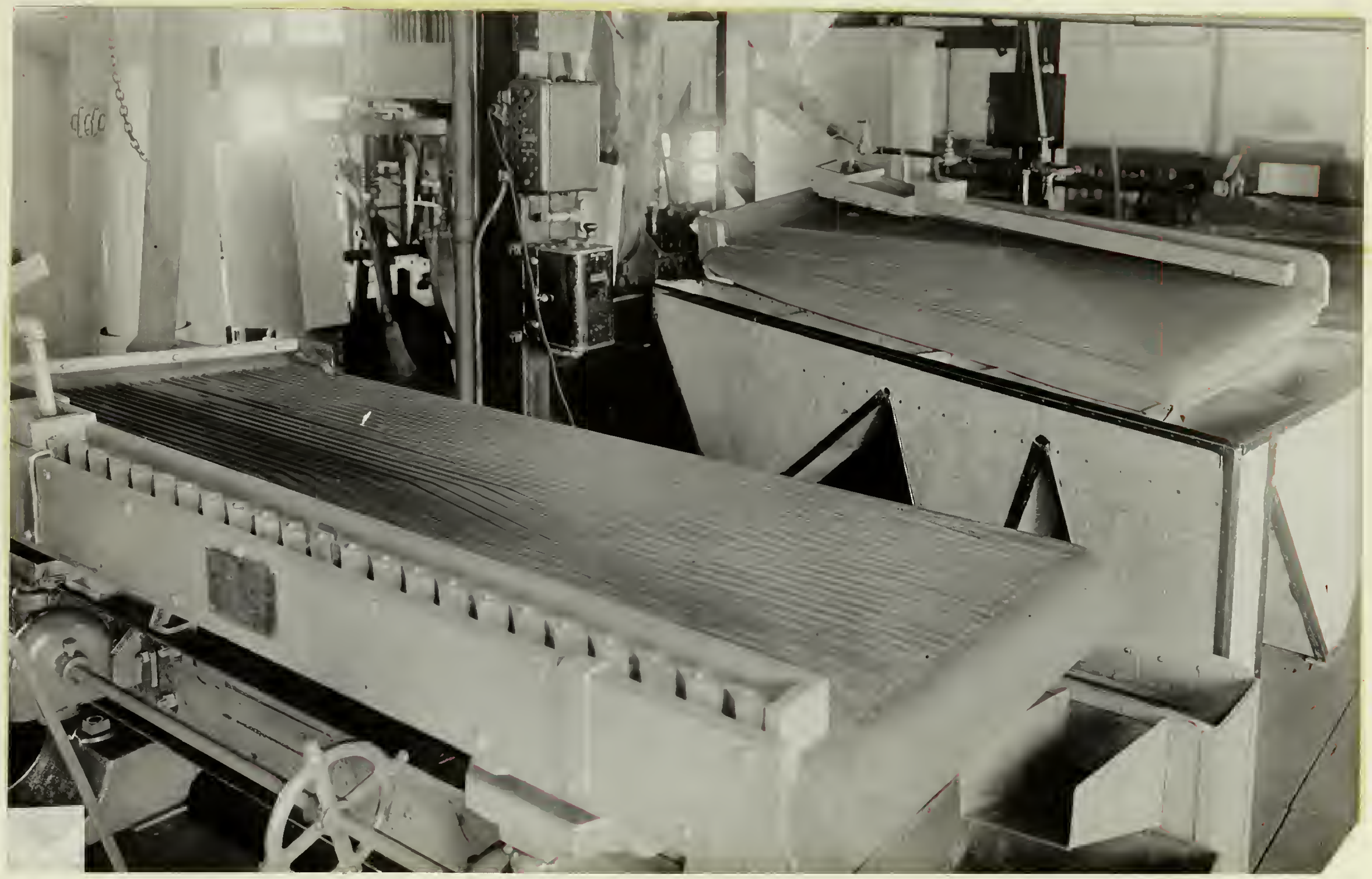

Fig. 23 - Coal Washing Tables in the Mining Laboratory

graph Fig. 23. The table in the foreground is a Butchart table manufactured by W. A. Butchart, Denver, Colorado, and the other is a Deister-Overstrom table manufactured by the Deister Concentrator Company, Fort Wayne, Indiana. The laboratory Butchart table is 7' 6" long by 3' 0" wide, giving a deck area of 22½ square feet. The Deister-Overstrom is 7' 3" long by 3' 3" wide with a deck area of 23½ square feet.

The special feature of the Butchart table is the shape of the riffle which has a curved portion in the middling zone so that the heavy material moving along the riffles toward the concentrates discharge edge has to climb in this curved section against the transverse inclination of the table deck. This facilitates the cleaning of the concentrate, which in coal washing is the refuse, and makes the line of separation of refuse from the coal more stationary as the coal cannot climb against the transverse flow of wash water. Also by moving the load of refuse farther up on the table toward the wash water launder, it increases the effective area of the cleaning zone and increases in a measure the capacity of the table. This effect is most apparent in the treatment of coals containing a large proportion of refuse. A similar effect is secured on the Plato table, manufactured by the Deister Machine Company, by making the concentrates climb against an inclination of the surface of the deck in the middling zone corresponding to the curved riffle portion of the Butchart deck.

The Deister-Overstrom table, which is the other machine shown in the photograph, secures an increased capacity and cleaning area by the diagonal deck feature. The deck of this table is shown in the drawing, Fig. 24. The raw coal feed box and middling dis-

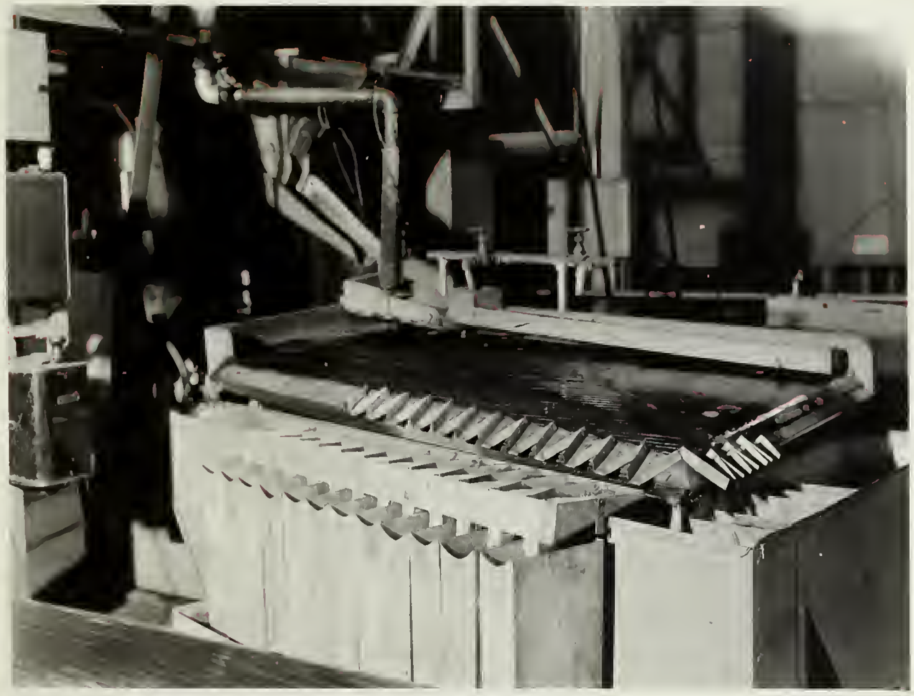

Fig. 24A- Coal Washing Table Showing Special Equipment Used

charge are at opposite corners on the long diagonal so that the middling particles and unseparated coal and refuse particles have to travel the maximum distance before being discharged as middling.

As shown in the illustration, Fig. 22, the tables in the laboratory discharge their products into galvanized tanks. From these tanks the water and coal are piped through the floor into settling cones from which the settled coal and refuse are drawn off into steam heated drying pans for sampling and weighing. The tanks are divided into compartments so that three products can be made in the Butchart table tests, and four can be made in tests on the Deister-Overstrom table. The division points between the various compartments are adjustable so that any desired separation may be made.

In order to make an intensive study of the disposition made by the table of the various kinds of particles as regards ash and sulfur content these two tables were equipped with a series of spouts along the refuse and the coal discharge edges to guide the discharging material into a number of separate sampling cans or compartments. The arrangement of this special equipment on the Deister-Overstrom table is shown in Fig. 23. The coal and refuse discharging around the side and end of the table may thus be divided into twenty products varying in quality from the cleanest coal to the cleanest refuse. The divisions were made closest together around the middling corner of the table because this is the region in which the separation between coal and refuse is made. Somewhat similar equipment was used by Richards[1] in making a study of the

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[1]Text book on Ore Dressing, p. 343.

operation of the Wilfley table on a quartz galena ore.

27. Comparison of the Work of the Experimental Table With That of the Commercial Size Table. In order to determine what value might be attached to the results secured in tests on the laboratory size tables, tests on duplicate samples were made on the full size table at the Deister Concentrator Company's testing plant and on the Deister-Overstrom table in the Mining Laboratory. These tests were made on an Indiana coal crushed to one-fourth inch maximum size. Results secured with the full size table are given in Table 12.

TABLE 12

Results Secured by Treatment of an Indiana Coal on the Commercial Size Deister-Overstrom Table

Product	Weight pounds	Per cent of feed	Per cent ash	Per cent sulfur
Raw coal	6444	100.0	16.5	3.85
Washed coal (Coarse)	5238	81.5	6.9	3.38
Sludge[1]	374	5.6	32.3	2.26
Refuse	832	12.9	63.7	5.95
Sample of washed coal including sludge			8.6	
Same calculated from sludge and coarse washed coal			8.55	
			.05 check	
Rate 5¼ tons per hour.				

The results of the test on the small laboratory table were given in Table 4 and Fig. 5 of the chapter on coal washing principles. The separation, which most nearly duplicated the work

[1]The Sludge is fine coal and dust draining from the washed coal as it is elevated to the storage bin by a dewatering drag conveyor.

of the large table, was between samples 13 and 14 giving a yield of 85.7 per cent of washed coal with an ash content of 8.7 per cent and sulfur content of 3.33 per cent, as compared with a yield on the large table of 87.1 per cent of washed coal with 8.6 per cent ash and 3.42 per cent sulfur.

This indicates that the laboratory size table will do about as good work in ash and sulfur reduction as the commercial size machine. The capacity of the small machine, however, is slightly smaller in proportion to its size than that of the large machine. The tonnages treated in the laboratory tests varied from 1200 pounds to one ton per hour, while the commercial size table, which has approximately five times the deck area of the experimental table, handles from five to eight tons per hour. There is also a difference in the size of material which the two tables will handle, as the large table will treat successfully a feed crushed to a maximum size of one-half inch round hole, while the largest size that the laboratory table will handle efficiently is three-eighths inch.

28. Tests On Herrin Coal. The sample of Herrin coal as received at the laboratory consisted of three inch screenings analyzing 12.2 per cent ash and 2.7 per cent sulfur. The visible impurities consisted of pieces of pyrite bands and lenses as much as one inch in thickness; thin hard shale bands, of the kind that do not disintegrate in water; a small amount of fine clay; thin plates of pyrite in joint fissures and an unusually large showing of calcite and gypsum in thin flakes.

Table 13[1] showing the bands of impurities occurring at

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[1]Analyses of Coal, U. S. Bureau of Mines Bull. 22, p. 513.

two places in this mine where face samples were taken by Bureau of Mines engineers will show the kind of impurities that have to be washed out.

TABLE 13

Sections of No. 6 Coal Bed at Herrin, Illinois, Big Muddy No. 7 Mine

	Section A Feet	Section A Inches	Section B Feet	Section B Inches
Roof, shale.				
Top coal (a).....................	1	7	--	------
Coal.............................	0	7	0	6
Sulphur (a)......................	--	------	0	¼
Mother coal......................	0	¼	--	------
Coal.............................	0	7	0	8
Shale, regular parting...........	--	------	0	1/8
Mother coal......................	0	1/8	--	------
Coal.............................	0	11	1	3
Mother coal......................	--	------	0	1/8
Shale and mother coal............	0	¼	--	------
Coal.............................	1	8	1	3
Sulphur..........................	--	------	0	1/8
Shale............................	0	1/8	--	------
Coal.............................	--	------	1	6
Mother coal......................	0	1/8	0	1/8
Coal.............................	1	4	1	7
Blue band (a)....................	0	1	0	2
Coal.............................	2	0	2	0
Floor, fire clay.				
Thickness of section............	8	9 7/8	8	11¾
Thickness of coal sample.......	7	1 7/8	8	9½

(a) Not sampled; not mined.

Of the 2.7 per cent of sulfur in the average raw coal used for the tests 0.8 per cent was in the organic form and 1.8 per cent was in the pyritic form with a trace of sulfate sulfur. Samples crushed to finer than one-eighth inch and carefully hand picked, using forceps and a magnifying glass, to discard all particles showing a trace of impurity on the surface, still contained an aver-

age of 4.0 per cent ash and 1.0 per cent pyritic sulfur.

The mine from which this coal came is on the edge of the low sulfur coal basis of Franklin and Williamson Counties as mapped out by G. H. Gady[1] who designates the mine samples as averaging between 1.25 and 1.50 per cent sulfur. Car samples and washery head samples taken at this mine at different times varied from less than one per cent to as high as three per cent in sulfur. This shows how erratic and uncertain is the sulfur content of this coal. This, according to the reports of coke oven and gas plant operators who have attempted to use Southern Illinois coals, is typical of the Franklin-Williamson County low sulfur coals. The greatest advantage of washing such a coal would be to make the ash and sulfur content more uniform.

For the washing tests the coal was crushed in toothed rolls to pass a one inch round hole screen and separated at one-fourth inch size. The over-size ¼" - 1" in size was washed on the experimental jig described above, and the under-size 0" - ¼" in size was washed on the Butchart table. Results of these tests are shown in Tables 14 and 15.

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[1] Mines Producing Low Sulfur Coal in the Central District, Ill. Geol. Survey Bull. 23.

TABLE 14

Jig Washing Test on Herrin Coal at $\frac{1}{4}$" - 1" size

Product	Weight pounds	Per cent of raw coal	Per cent ash	Per cent sulfur
Raw coal	385.0	100.0	11.0	2.70
Washed coal	344.0	89.5	7.7	1.89
Middling	5.0	1.3	36.5	5.85
2nd Hutch (Sludge)	8.0	2.0	16.2	3.77
Refuse	18.8	4.9	48.5	10.90
1st Hutch (Fine refuse)	2.0	0.5	80.2	2.69
		98.2		
Loss		1.8		

TABLE 15

Washing Test on Herrin Coal; 0" - $\frac{1}{4}$" size; Butchart Table

Product	Weight pounds	Per cent of raw coal	Per cent ash	Per cent sulfur
Raw coal	205.0	100.0	14.2	2.70
Washed coal	161.0	78.5	7.2	1.85
Middling	16.0	7.8	19.8	2.56
Washed coal & Middling	177.0	86.3	8.1	1.90
Refuse	13.0	9.5	72.1	10.75
Loss		4.8		

In these tests the jig showed a washed coal yield of 89.5 per cent with an ash reduction of 29 per cent and a sulfur reduction of 30 per cent, while the table showed a yield of 86.3 per cent with an ash reduction of 43 per cent and a sulfur reduction of 30 per cent. The raw coal feed on the two tests was not identical in ash content so that the tests are not perfectly comparable, but taking this fact into consideration the degree of separation secured in the two tests is about the same. The greater reduction in ash

[illegible]

and the lower yield in the table test are explained by the higher ash content of the feed. The efficiencies as compared with sink and float separation taking float on solution of 1.35 specific gravity as standard washed coal, are 67 per cent for the jig test and 69 per cent for the table test.

A complete specific gravity analysis of the 0" - ¼" raw coal is given in Table 16.

TABLE 16

Specific Gravity Analysis of Herrin Coal at 0" - ¼" size

Specific Gravity	Per cent of sample	Per cent ash	Per cent sulfur
Lighter than 1.30	73.35	4.64	1.72
1.30 to 1.35	8.74	11.27	2.14
1.35 to 1.40	4.93	17.78	2.39
1.40 to 1.45	1.82	20.32	2.52
1.45 to 1.50	0.39	24.60	2.62
1.50 to 1.60	1.12	29.90	2.80
1.60 to 1.80	2.13	49.53	3.43
Heavier than 1.80	7.52	84.04	13.63

In order to more easily interpret these figures, graphs, Fig. 25 and Fig. 26, have been drawn to show the distribution of impurities in the coal according to density. Beginning at the top, the ordinate line is divided into parts proportional to the percentages of the different specific gravity products beginning with the lightest. The total length of the ordinate axis thus represents the total weight of raw coal 100 per cent. Midway of the ordinate for each specific gravity increment of the sample its average ash or sulfur content is laid off as the abscissa. Vertical lines drawn through these points gives a graph, showing the distribution of ash or sulfur in the raw coal, and the area between the graph and

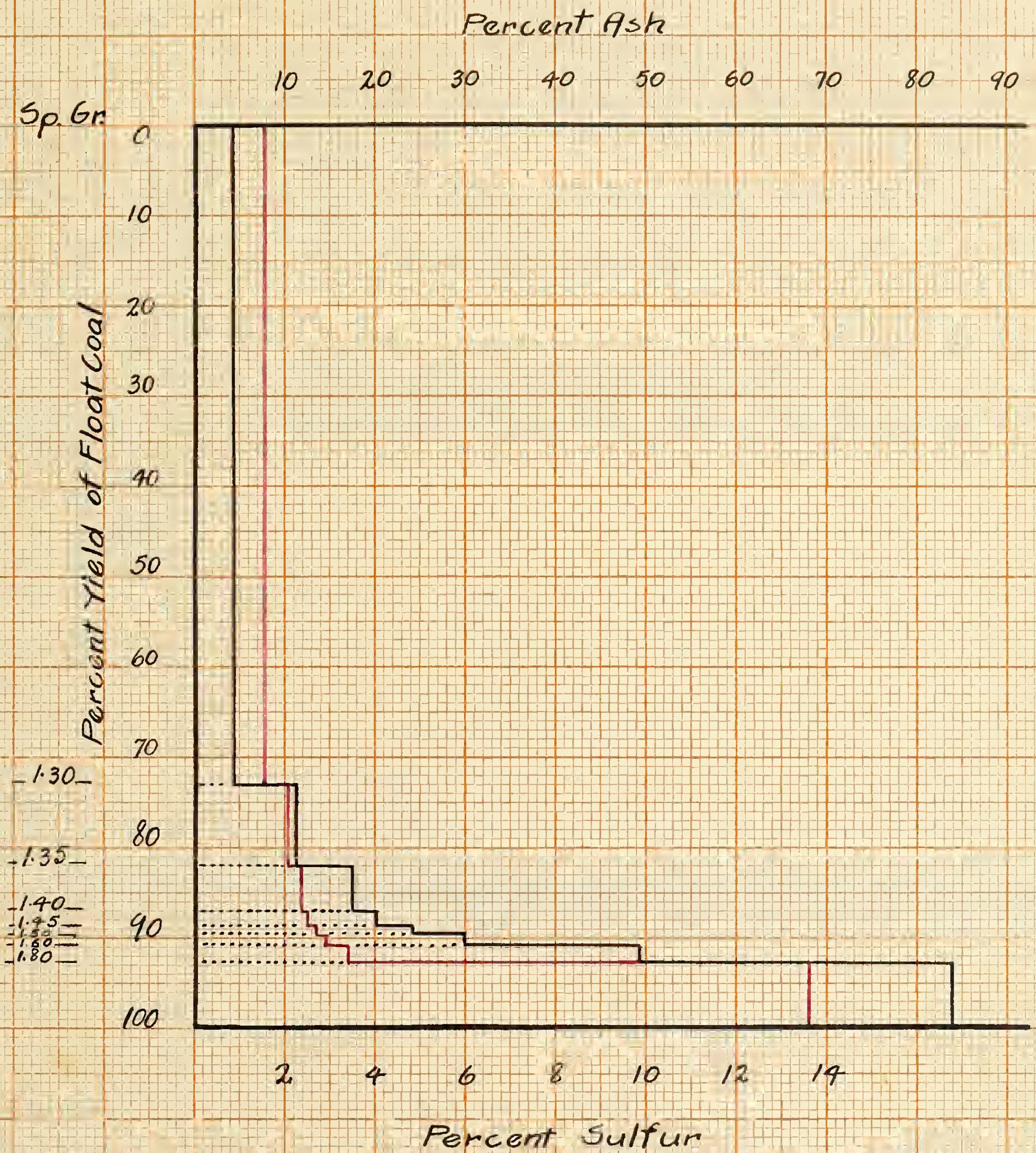


Fig. 25 — Specific Gravity Analysis
Herrin Coal

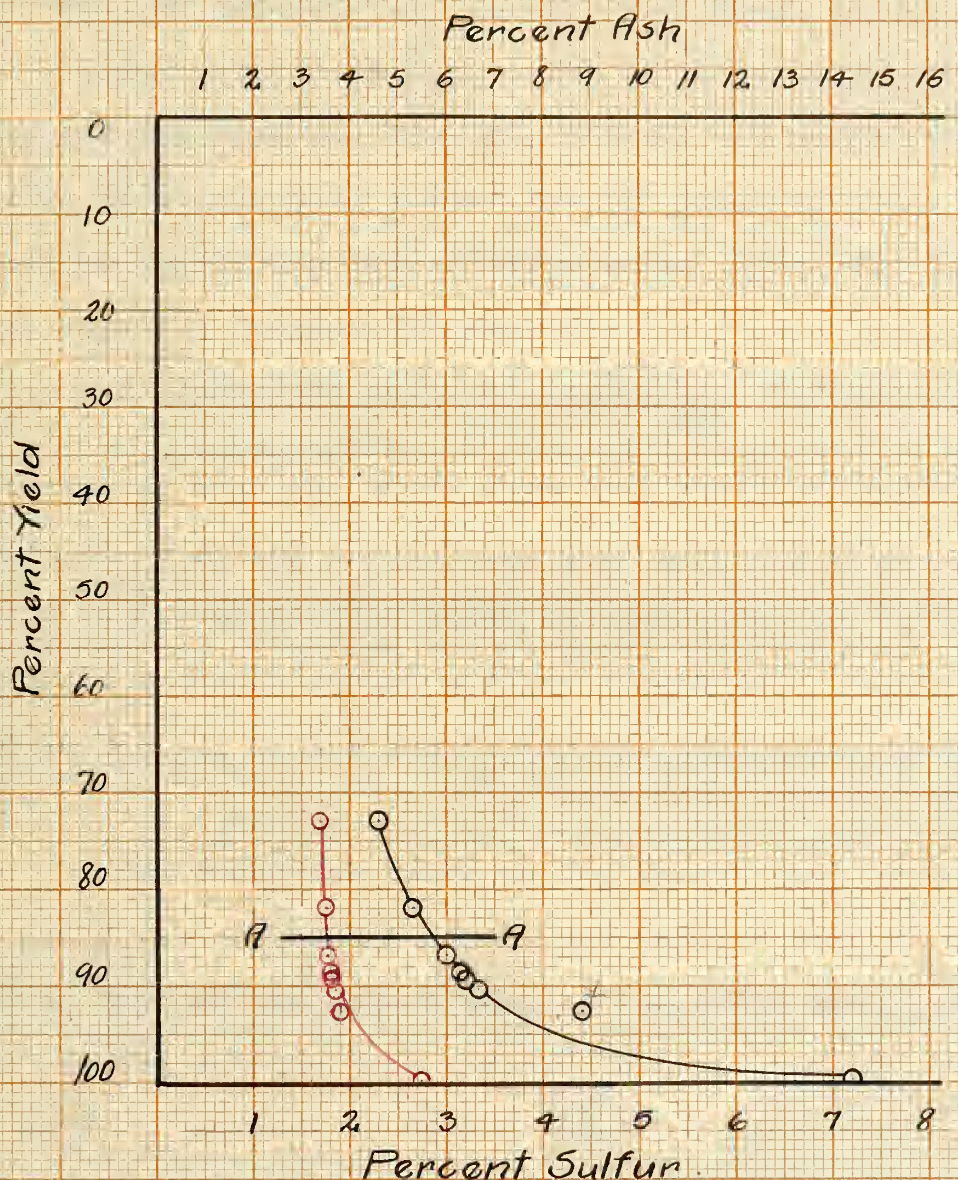


Fig. 26—Theoretical Yield Curves
Herrin Coal

the axis shows the weight of ash or sulfur in the sample of weight 100. The mean abscissa is the raw coal ash or sulfur.

The purpose of this curve is to determine where to make the separating line AA, Fig. 26, between the refuse and clean coal in order to obtain best values for "Y" yield of clean coal and for "X" ash or sulfur content of clean coal. Obviously there is a functional relation between "X" and "Y".

Plotting the curve of $X_n = \frac{\sum_o^n X.Y}{Y_n}$ for ash and sulfur gives the curves of Fig. 26, which show what yield corresponds to any required ash or sulfur content and what ash or sulfur content may be secured in any proportion taken as clean coal on the basis of sink and float or theoretically perfect separation. These theoretical yield curves are called the "Float-ash curve and the float-sulfur curve".

The float-ash curve on the Herrin coal shows a yield by sink and float separation, of 91 per cent of coal of an ash content equal to that of the washed coal of the table test, namely, 7.2 per cent. As the washing test yielded 78.5 per cent of washed coal this shows a recovery of $\frac{78.5}{91}$ or 86.2 per cent of the good coal of this quality present in the raw coal. Comparing the yield of washed coal plus middling, making a washed coal of 8.1 per cent ash content, with the float-ash curve shows a recovery by washing of $\frac{86.3}{92}$ or 93.8 per cent of this material available in the raw coal.

29. Bon Air Coal. For the tests on coal from this seam a sample of run of mine coal from the Eastland Mine of the Bon Air Coal and Iron Company was used. This sample as received at the laboratory in Urbana was of rather fine size; 89.5 per cent passed through a two inch round hole screen. Analysis of a moisture-free

sample showed a sulfur content of 4.87 per cent and 15.5 per cent ash. Notwithstanding this high ash and sulfur analysis, visual examination showed very little free dirt. This indicates that the impurities are intimately mixed with the coal.

The object of the experimental work on this particular coal was to determine to what extent the sulfur content can be reduced. Several years ago attempts were made to lower the sulfur in this coal by washing with jigs, in order to produce a more suitable coal for the Bon Air Coal and Iron Company's coke ovens at Eastland, but these attempts were unsuccessful. The experiments made at Urbana constitute a second attempt to produce a low sulfur coal by using newer and more improved methods of washing.

The results of screening tests given in detail in Table 17 shows the sulfur to be very evenly distributed through the sizes and that nothing is to be gained by screening out either the coarse or fine sizes. Sink and float tests made on these sized products and on original raw coal samples crushed to one-half inch and one-fourth inch maximum sizes, using zinc chloride solution of 1.45 specific gravity, all showed very poor results in the way of ash and sulfur reduction, the float in every case analyzing three per cent or more in sulfur and over eleven per cent ash. This shows conclusively that due to the high residual ash and sulfur it is impossible to make a high grade coking coal by washing this material.

TABLE 17

Screening Test on Bon Air Run of Mine Coal as Received

Size	Weight pounds	% of total	% sulfur
On 2" round hole	5.24	10.5	4.44
On 1" round hole	14.52	29.3	4.46
On ½" round hole	11.40	23.2	4.93
On ¼" round hole	8.30	16.7	4.41
On 1/8" round hole	4.56	9.2	4.41
Through 1/8" round hole	5.50	11.1	4.20
Head sample	49.52	100.0	4.87

TABLE 18

Sink and Float Tests on Bon Air Coal Solution
Used 1.45 specific gravity

Sink	% float	% sulfur in float	% sink	% sulfur in sink
1" - 2"	92.6	3.34	7.4	18.80
½" - 1"	88.5	3.12	10.9	17.08
¼" - ½"	88.0	3.07	12.0	14.40
1/8" - ¼"	87.6	3.17	12.4	13.37
0" - 1/8"	82.5	2.99	17.5	9.95
0" - ½" (crushed)	90.5	3.22	9.5	20.7
0" - ¼" (crushed)	92.1	3.51	7.9	21.7

As a visual examination showed very little visible coarse pyrite and these sink and float tests indicated an advantage in the fine sizes, of a higher yield of float coal and cleaner refuse in the sink, the entire sample was crushed to a maximum size of three-eighths inches before washing. Table 19 gives the results of a complete specific gravity analysis made on the raw coal at this size. The float-ash and the float-sulfur curves are shown in Fig. 27.

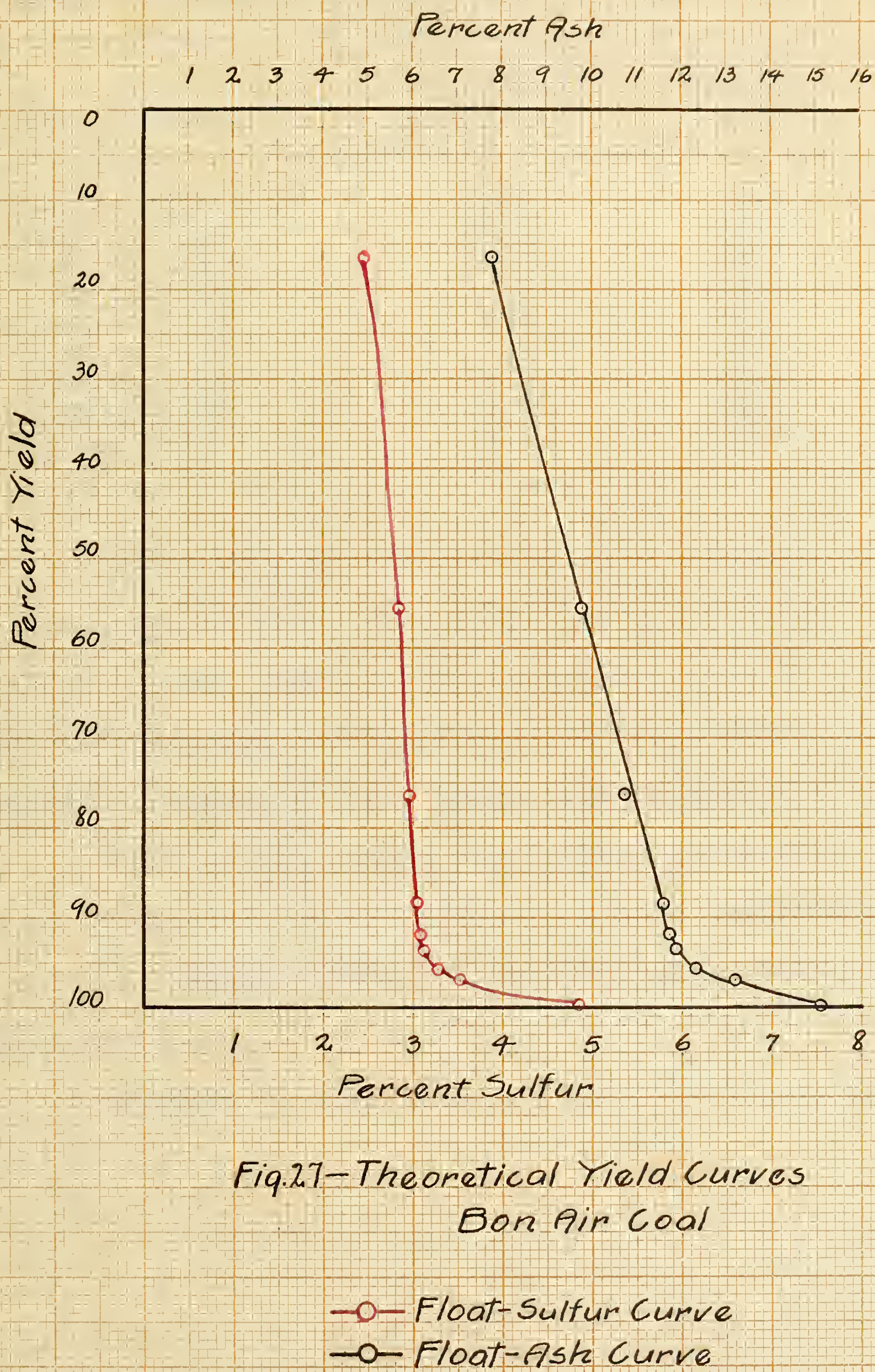


Fig. 27 — Theoretical Yield Curves
Bon Air Coal

TABLE 19

Specific Gravity Analysis Bon Air Coal at 0" - 3/8" Size

Specific Gravity	Per cent of total	Per cent ash	Per cent sulfur
Lighter than 1.26	16.3	7.8	2.44
1.26 to 1.30	39.6	10.6	3.01
1.30 to 1.35	20.5	13.3	3.35
1.35 to 1.40	11.8	15.4	3.45
1.40 to 1.45	3.8	19.1	4.39
1.45 to 1.50	1.8	22.5	6.18
1.50 to 1.60	2.1	27.6	9.20
1.60 to 1.80	1.1	42.7	13.30
Heavier than 1.80	3.0	60.5	34.12

Float on 1.45 was designated as standard washed coal in this case because above this point the curve shows a rapid increase in sulfur and ash content with increasing specific gravity and to reject any material lighter than 1.45 would result in only a small reduction in impurity for a large loss in yield of washed coal.

Part of the sample was washed on the experimental jig with an artificial bed of feldspar in each compartment. The other portion was treated on the Deister-Overstrom and the Butchart concentrating tables.

Results of the tests are given in Tables 20, 21 and 22.

TABLE 20

Feldspar Jig Test on Bon Air Coal

Heads	166 lbs.
15.15% ash	4.87% sulfur
0" - 3/8" size	rate 1660 lbs. per hr.

Clean Coal	First Hutch	Second Hutch	Loss
144 lbs.	6 lbs.	5 lbs.	11 lbs.
86.9 % of feed	3.6 % of feed	3.0 % of feed	6.5% of feed
3.8 % sulfur	22.3 % sulfur	10.63% sulfur	
13.37% ash	49.52% ash	30.97% ash	

TABLE 21

Bon Air Coal, Test on Deister-Overstrom Table

Feed 552 lbs. 15.15% ash. 4.87% sulfur.
Size 0" - 3/8" rate 1380 lbs. per hour.
235 r.p.m. 13/16" stroke.

Refuse 89 lbs.
16.1% of feed
8.97% sulfur
63% float on 1.40

3'3" | 2'3" | 2'0"

Sample 1 Sample 2 Sample 3 | Sample 4

No. 1 coal 118 lbs.	No. 2 coal 118.5 lbs.	No. 3 coal 187.3 lbs.
21.4 % of feed 3.09% sulfur 11.38% ash	21.5 % of feed 3.05% sulfur	34.0 % of feed 3.98% sulfur

No. 1 and No. 2 coal: 42.9% of feed 3.07% sulfur

No. 1, No. 2 and No. 3 coal: 76.9 % of feed 3.48% sulfur

Loss 39.21 lbs. 7.0% of feed

# Sample 1	2.9 %	sulfur
" 2	2.67%	"
" 3	2.94%	"
" 4	3.31%	"

#These samples taken during the test by catching overflow in pans twelve inches wide as shown on diagram above.

TABLE 22

Bon Air Coal Test on Butchart Table

Feed 159 lbs.; 15.15% ash; 4.87% sulfur.

Size 0" - 3/8"; rate 795 lbs. per hour.

235 r.p.m.

Refuse 13 lbs.
8.2 % of feed
17.74% sulfur
43.39% ash

No. 1 coal 87 lbs.
54.6% of feed
11.3% ash 3.02% sulfur

No. 2 coal 51 lbs.
32.0 % of feed
5.22% sulfur
17.95% ash

86.6% of feed. 3.82% sulfur

Loss 8 lbs. 5.2%

In both table tests it was very difficult to determine the proper line of separation between coal and refuse, as very few pure shale or pyrite particles separated out. The refuse from the first table test looked like coal and 63 per cent of it floated on 1.40 specific gravity solution.

In the second table test a small refuse product was taken and this contained a much smaller percentage of coal. Only 20.5 per cent floated on 1.40 specific gravity solution, but the secondary coal in this test was much dirtier than in the first table test.

The impurity in this coal is not present as shale and pyrite pieces but as impure particles of high ash and sulfur content, and in order to produce the cleanest product possible, namely, 3.0 per cent sulfur and about 11.0 per cent ash, it is necessary to take out a large percentage of the raw coal, consisting of these impure coal particles, with the refuse or intermediate products. By this means a reduction in sulfur of 38 per cent may be secured in a No. 1 coal product amounting to 55 per cent of the raw coal. This shows the impossibility of producing a high grade coking coal from this material by any process of mechanical separation. Analysis showed an organic sulfur content of 1.16 per cent which precludes the possibility, even if all the pyritic sulfur could be eliminated, of producing a coal lower in sulfur than 1.16 per cent.

Comparing the jigging test with the table tests, it is evident that the two methods were about equally effective in making a clean separation as the jig test and the second table test both give washed coal products amounting to 86.6 per cent of the feed and analyzing 3.8 per cent sulfur. In the first table test no product or combination of products comparable with these were taken.

The efficiencies as compared with sink and float separation at 1.45 specific gravity are 56.0 per cent for the jig test and the second table test.

The yields secured in the washing tests, by comparison with the yield of equivalent products by specific gravity analysis shows recoveries as follows:

In the jig test $\frac{86.6}{97} = 89$ per cent

In the first table test, considering the combined No. 1, No. 2 and No. 3 coal, $\frac{76.9}{94} = 82$ per cent

30. Tests On Clover Run Coal. The shipment of Clover Run coal on which the experimental work was done was received from the two mines of Madiera Hill and Company at Mahaffey, Pennsylvania. A careful visual examination showed very little free pyrite, but considerable amounts of carbonaceous shale and slate. When received the coal had been crushed to such a size that 98.5 per cent of it passed through a one inch round hole screen. It contained an average of one-half per cent moisture, 12.8 per cent ash and 3.48 per cent sulfur, consisting of 2.77 per cent pyritic sulfur and 0.71 per cent of organic sulfur. Sulfate sulfur was entirely absent or present only in minute traces. The sample was secured by mining, by hand, from five to six hundred pounds of coal from each of ten working faces. These portions were then crushed by hand, thoroughly mixed and reduced by coning and quartering to about 2,500 pounds.

In order to gain some idea as to the size at which this coal might be most successfully washed and to determine roughly what percentage of the raw coal should be removed in the refuse and in the middlings, in order to produce a good clean coal, screening

tests and specific gravity tests were made. Results are shown in Tables 23 and 24.

The data in Table 23 were secured by hand screening a representative sample of 128.5 pounds on half inch and quarter inch round hole screens and analyzing the sized products.

TABLE 23

Sizing Test on Clover Run Coal as Received

Size	Weight pounds	% of total	% ash	% sulfur
0" - ¼"	62.5	48.5	10.42	3.56
¼" - ½"	36.5	28.4	12.46	3.40
½" - 1"	27.5	21.6	16.27	3.64
Over 1"	2.0	1.5	-----	----
Total	128.5	100.0	12.80	3.48

For the sink and float tests, Table 24, samples of the sized coal from the screening test, described above, were used. By immersing in heavy solutions of zinc chloride the samples were divided into three classes of material; Particles lighter than 1.35 in specific gravity; those between 1.35 and 1.60 in specific gravity; and those heavier than 1.60 in specific gravity. These represent approximately the clean coal, middling and refuse naturally occurring in the raw coal samples. The percentage of each of these three classes of material with their ash and sulfur content in each size of raw coal is shown in Table 24.

TABLE 24

Clover Run Coal Sink and Float Tests

Product	% of total	% ash	% sulfur
	Size ½" - 1"		
Float 1.35 Sp. G.	55.2	7.0	1.19
Middling 1.35 to 1.60	29.2	17.0	4.00
Sink in 1.60	14.5	51.31	13.34
	Size ¼" - ½"		
Float 1.35 Sp. G.	72.0	5.8	1.23
Middling 1.35 to 1.60	19.3	22.9	5.30
Sink 1.60	7.5	50.4	19.85
	Size 0" - ¼"		
Float 1.35 Sp. G.	85.1	4.8	1.20
Middling 1.35 to 1.60	7.3	34.0	13.6
Sink 1.60	7.6	47.7	19.27

The information of importance furnished in this Table is in the figures showing the percentage of natural middlings, material between 1.35 and 1.60 specific gravity, in the three sizes of raw coal, i.e., ½" - 1", 29.2 per cent; ¼" - ½", 19.3 per cent and 0" - ¼" only 7.3 per cent. This indicates that fine crushing is necessary in order to break the fine particles of refuse free from the particles of clean coal, thus reducing the percentage of middlings, pieces part coal and part refuse.

In the washing tests three methods of treatment were tried.

1. A sample of 1292 pounds of the raw coal was screened on a quarter inch round hole screen. The oversize ¼" - 1" in size was jigged and the undersize 0" - ¼" was treated on a coal washing table.

2. A sample of 383 pounds of the raw coal was crushed to three-eighths inch maximum size and washed on the table.

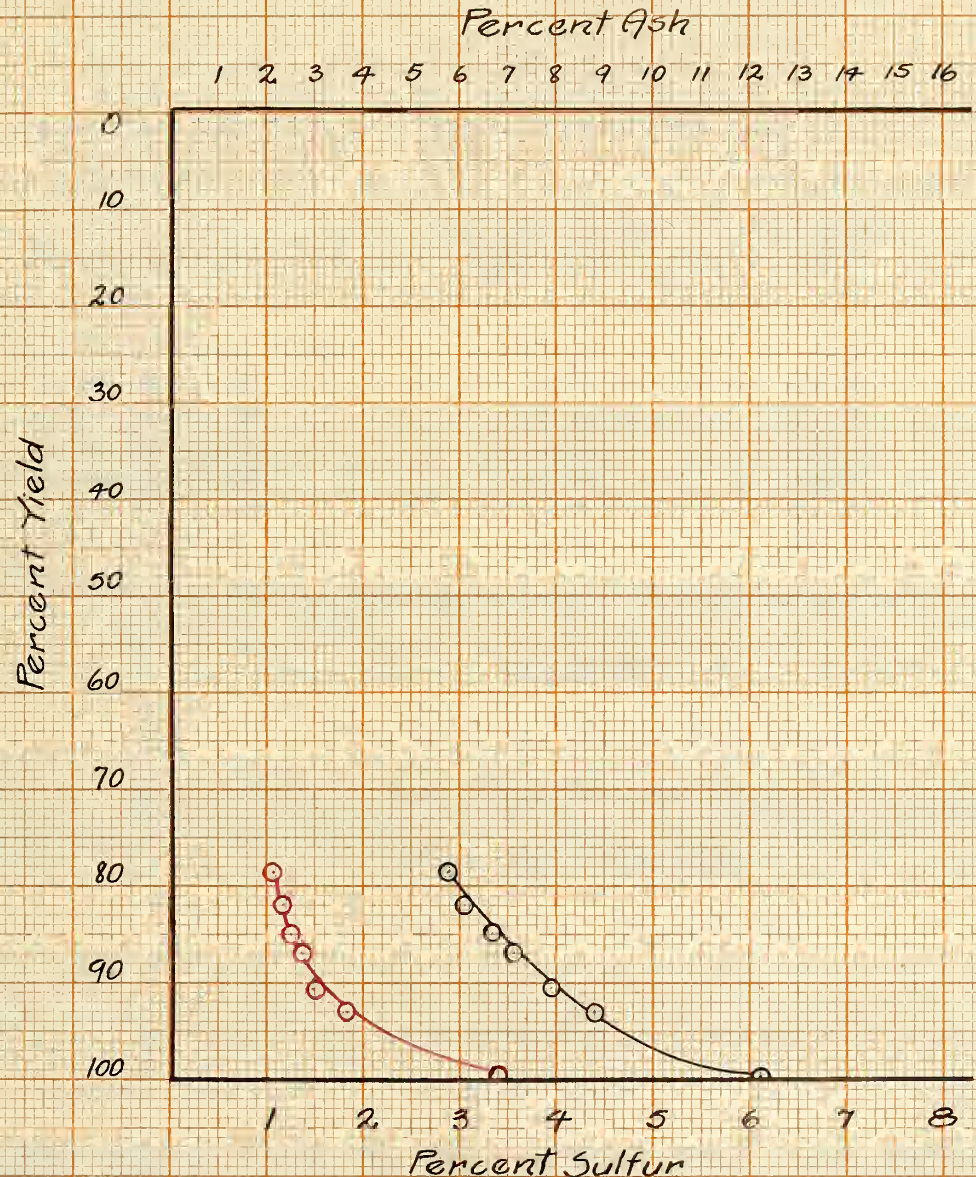


Fig. 28—Theoretical Yield Curves
Clover Run Coal

3. Four hundred twenty-four pounds of the raw coal was treated, just as received without sizing, on the jig.

TABLE 25

Specific Gravity Analyses Clover Run Coal at 0" - 3/8" Size

Specific Gravity	Per cent in raw coal	Per cent ash	Per cent sulfur
Lighter than 1.35	78.2	4.8	1.07
1.35 to 1.40	3.7	12.3	2.20
1.40 to 1.45	3.4	19.8	3.18
1.45 to 1.50	2.0	25.2	4.13
1.50 to 1.60	3.2	30.7	4.68
1.60 to 1.80	2.7	34.3	7.47
Heavier than 1.85	6.8	57.3	28.00

TABLE 26

Jig Test on Clover Run Coal

Coal as received with 0" - $\frac{1}{4}$" material removed

674# $\frac{1}{4}$" - 1" size

3.50% sulfur 14.10% ash

Washed Coal	Middlings	Refuse
572 lbs. 85% of feed 2.34% sulfur 11.43% ash	61 lbs. 9.0% of feed 4.48% sulfur 16.09% ash	Bed product and hutch 41 lbs. 6% of feed 18.29% sulfur 48.08% ash

Washed Coal + Middlings: 633 lbs. 94% of feed
2.55% sulfur 11.9% ash

Time 16 minutes. Strokes 172 per minute.
Rate 3600 lbs. per sq. ft. screen area per hour.

Efficiency assuming float on 1.35 as standard washed coal 63 per cent.

Table 27- Jig test on 0" - 1" Clover Run Coal

424 lbs. Feed 0-1" size
3.48% Sulfur 12.8% ash

Washed Coal	Secondary Coal Coarse	2nd Hutch Secondary Coal	Coarse Refuse	1st Hutch Refuse	Loss
305 pounds	45 pounds	25 pounds	17 pounds	6 pounds	26 pounds
72% of feed	10.6% of feed	4.9% of feed	4% of feed	1.4% of feed	6.1% of feed
2.02% sulfur	6.48% sulfur	4.68% sulfur	16.87% sulfur	20.5% sulfur	
9.82% ash	21.92% ash	13.4% ash	45.0% ash	42.4% ash	

Time 6 minutes. Strokes 172 per minute.
Rate 5900 lbs. per sq. ft. screen area per hour.

Efficiency, assuming float on 1.35 as standard washed coal 44 per cent

TABLE 28

Table Washing Test 0" - ¼" Clover Run Coal

Deister-Overstrom Diagonal Deck Coal Washing Table

Product	Weight pounds	Per cent of feed	Per cent ash	Per cent sulfur
Raw coal	618	100.0	10.42	3.56
No. 1 Washed coal	389	63.0	5.27	1.31
No. 2 Washed coal	120	19.5	9.10	1.82
No. 3 Coal	40	6.5	20.20	5.30
No. 1 and No. 2	509	82.5	6.17	1.43
No. 1 No. 2 No. 3	549	89.0	7.20	1.72
Refuse	40	6.5	48.42	21.73
Loss	29	4.5		

Strokes per minute 235.
Time 21 minutes.
Rate 1850 lbs. per hour.

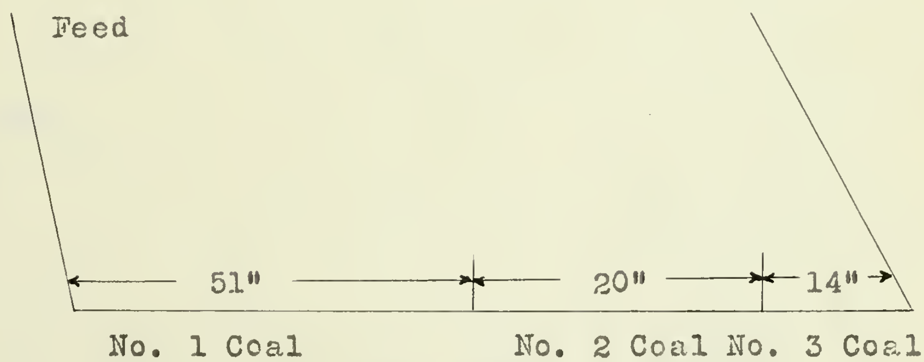


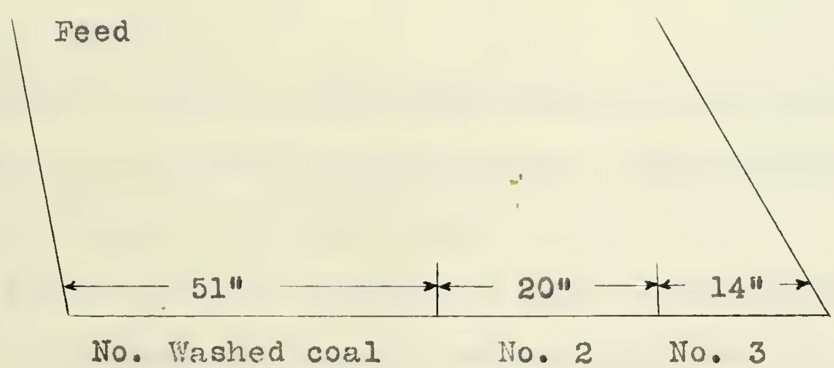
TABLE 29

Table Washing Test on Raw Coal Sample Crushed
to 3/8" Maximum Size

Deister-Overstrom Diagonal Deck Coal Washing Table

Product	Weight pounds	Per cent of feed	Per cent ash	Per cent sulfur
Raw coal	383	100.0	12.80	3.48
No. 1 Washed coal	286	74.7	7.90	1.53
No. 2 Washed coal	45	11.8	17.19	4.17
No. 3 Washed coal	7	1.8	40.35	11.41
No. 1 and No. 2	331	86.5	9.17	1.89
No. 1 No. 2 No. 3	328	88.3	9.80	2.09
Refuse	24	6.3	52.13	23.74
Loss	21	5.4		

Strokes 235 per minute.
Rate 1915 lbs. per hour.



Results of the two jig tests on Clover Run coal are given in Tables 26 and 27. The low efficiency secured in the second test was due to the fine material present in the unsized feed. Apparently the material below one-fourth inch ring size was not handled efficiently in this test and the sink and float tests showed in this size a very complete separation with a very small middling product, a high yield of float coal and a large reduction in sulfur content. As compared with these sink and float results, the separation in the jig was poor. On the other test, where the raw coal was screened at one-fourth inch and the fine coal and the coarse coal were washed separately, the efficiency of the jig on the ¼" - 1" feed was 63 per cent as compared with an efficiency of 44 on the 0" - 1" feed unsized. The average sulfur content of the washed coal, fine and coarse combined, was 1.93 per cent with a yield of 74.5 per cent as compared with a 72 per cent yield of washed coal of 2.02 per cent sulfur on the 0" - 1" jig test. This shows a slight advantage in sizing before washing.

The jig tests on this coal were not as successful in reducing sulfur as the table washing tests. The preliminary sink and float tests indicated that this would be the case as the large sizes ¼" - ½" and ½" - 1" contained a much larger percentage of material of intermediate density, between 1.35 and 1.60 specific gravity, than the finer material under ¼" size. This is the material which forms middlings, pieces part coal and part refuse, which require finer crushing in order to free the particles of refuse and coal. All these tests indicate the necessity of fine crushing.

In conducting the table washing tests, from three to five products were made for analysis in order to get as complete data

as possible on the separation being secured. Composite figures showing what the results would be if only two products were made are arrived at by combining the products as desired and calculating the average ash and sulfur content. In the table tests division of the product into four grades, No. 1 coal, No. 2 coal, No. 3 coal, and refuse, was accomplished by dividing the material being discharged over the end and side of the table at suitable points as shown in the diagrams in Tables 28 and 29.

By washing with the table the pyritic sulfur content was reduced 70.4 per cent in the 0" - 3/8" No. 1 coal and 78.4 per cent in the 0" - ¼" No. 1 and No. 2 coal. These reductions of pyritic sulfur are large and the high reduction in total sulfur obtained by washing was made possible because only a small percentage of the total sulfur in the raw coal is present as organic sulfur.

The efficiencies were 74 per cent for the 0" - ¼" test and 80 per cent for the 0" - 3/8" test.

31. Tests On West Virginia Coal. The West Virginia coal used for washing tests was mined at Ramage, in Boone County. The sample received was taken by employees of the company who were instructed to take a sample representative of a full day's output of the mine. An official of the company, who was present when the tests were made, stated that this particular sample was somewhat higher in sulfur than the average for coal from this mine. The coal was very hard and when crushed to about three inches maximum size showed very little free pyrite and little or no slate or shale. It contained 2.48 per cent sulfur and 6.81 per cent ash on the moisture free basis. The mine operates in the Eagle seam of the Kanawha Group. The average of ten analyses on samples from the same seam

and county by the West Virginia Geological Survey show only 0.79 per cent sulfur.[1]

For some time past this coal has been used by a steel company for making producer gas, the gas being used in open hearth furnaces. Recently variations of sulfur in coal from this mine have caused difficulty in using it because of the high sulfur content of the gas. The purpose of the work described here was to determine whether or not the sulfur in this coal could be reduced low enough to make it suitable for open hearth fuel upon gasification.

In all the tests carried out the sulfur content of the cleanest coal obtained was well above the maximum figure designated by the operator as satisfactory. The cleanest coal secured analyzed 1.65 per cent sulfur. This product,more-over, amounted to only one-third of the original raw coal fed to the washer and also was crushed to three-eighths inch maximum size, which is finer than is desirable for producer gas fuel. The sulfur content of the No. 1 washed coals secured by jigging at suitable size for gas producer use, namely, 0" - ¾" was 1.98 and 2.00 per cent. These products again represented recoveries of only 84 per cent and 76 per cent, respectively. At the 0" - ¾" size a product consisting of 91.4 per cent of the raw coal analyzed 2.06 per cent sulfur, and in the 0" - 3/8" size a product carrying 2.01 per cent sulfur amounted to 92.7 per cent of the raw coal.

The plan followed in the examination of this coal was similar to that described in the discussion of the tests on the

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[1]White, I. C., Geographical Distribution of Sulfur in West Virginia Coal, Am. Inst. Min. and Met. Eng. Bull. 153, p. 2200, 1919.

Clover Run Coal. Table 30 shows the screen analysis on raw coal crushed to three-fourths inch maximum size and Table 31 shows results of the sink and float tests on the sized products of the screening tests.

TABLE 30

Screen Analysis, Spruce River Coal

Size	Weight pounds	% of total	% ash	% sulfur
½" - ¾"	42	39	6.83	2.66
¼" - ½"	36	33	6.28	2.42
0" - ¼"	30	28	6.64	2.31

TABLE 31

Sink and Float Tests, Spruce River Coal

Product	% of sample	% ash	% sulfur
Size ½" - ¾"			
Float on 1.35 Sp. G.	89.5	4.0	1.78
Middling 1.35 to 1.80	7.5	26.8	6.40
Sink in 1.80	2.7	47.3	22.21
Size ¼" - ½"			
Float 1.35 Sp. G.	91.0	4.0	1.68
Middling 1.35 to 1.80	5.5	18.7	10.50
Sink in 1.80	3.3	49.2	15.06
Size 0" - ¼"			
Float 1.35 Sp. G.	94.6	4.1	1.84
Middling 1.35 to 1.80	1.7	26.0	7.00
Sink in 1.80	3.2	52.7	14.07

TABLE 32

Specific Gravity Analysis, Spruce River Coal
at 0" - 3/8" size

Specific Gravity	Weight grams	% of total sample	% ash	% sulfur
to 1.25	2369	51.2	2.12	1.15
1.25 to 1.30	1529	33.0	3.68	1.36
1.30 to 1.35	420	9.1	12.43	3.55
1.35 to 1.40	44	1.0	14.20	3.36
1.40 to 1.45	43	.9	19.75	4.38
1.45 to 1.50	30	.6	23.20	4.41
1.50 to 1.60	39	.9	28.63	5.25
1.60 to 1.80	62	1.3	37.82	5.68
1.80	90	2.0	67.27	17.95
Total	4626	100.0		

In the washing tests four methods of treatment were tried.

1. A sample of 828 pounds of the raw coal, crushed to ¾" maximum size, was screened on a quarter inch round hole screen. The oversize 0" - ¼" was treated on a coal washing table.

2. Eight hundred forthy-two pounds of the raw coal crushed to pass a ¾" round hole screen was treated without sizing on the jig.

3. A sample of 292 pounds of the raw coal was crushed to 3/8" maximum size and washed on the table.

4. In order to determine the distribution of impurities in the coal as discharged from the washing table and to compare the results secured by table washing coal of 0" - 3/8" in size with results secured by close sizing, a sample of this coal crushed to 3/8" maximum size was screened on 1/8" and ¼" round hole screens and the three sizes 0" - 1/8", 1/8" - ¼", and ¼" - 3/8" were washed separately on the concentrating tables using the special equipment for separating the product into nineteen samples.

In conducting tests 1, 2 and 3, from three to five products were made for analysis in order to get as complete data as possible on the separation being secured. Composite figures show-

Table 35- Spruce River Coal -0" 3/4" Jig Test

Heads 841 lbs.
2.48% Sulfur 6.81% Ash

Washed Coal	Middlings Secondary Coal	2nd Hutch Secondary Coal	Refuse Coarse	1st Hutch Refuse	Loss
700.5%	48.5 lbs.	16 lbs.	19 lbs.	15 lbs.	42 lbs.
1.98% sulfur	3.12% sulfur	18% of heads	10.10% sulfur	5.46% sulfur	4.8% of feed
5.31% ash	12.87% ash	2.6% sulfur	34.2% ash	26.0% ash	
84.0% of heads	5.6% of heads	11.02% ash	2.1% of feed	1.7% of feed	

Washed Coal and Middlings combined: 91.4% of feed, 2.06% sulfur, 5.95% ash

Refuse Coarse and 1st Hutch Refuse combined: 3.8% of feed, 8.2% sulfur, 30.6% ash

Time 19 minutes
172 strokes per minute
Rate 3650 lbs. per sq. ft. of screen area per hour

Efficiency on basis of float on 1.35 as standard washed coal, 53%.

Table 36 - Spruce River Coal 1/4" - 3/4" Jig Test

Feed 598 lbs.
2.56% sulfur 6.91% ash

Washed Coal	Middlings Secondary Coal	2nd Hutch Secondary Coal	Refuse	1st Hutch Fine Refuse	Loss
498 lbs.	28 lbs.	4 lbs.	18 lbs.	15 lbs.	35 lbs.
2.04% sulfur	4.15% sulfur	0.7% of feed	3.0% of feed	8.10% sulfur	5.6% of feed
5.56% ash	14.50% ash	2.66% sulfur	13.0% sulfur	30.84% ash	
83.5% of feed	4.7% of feed	15.73% ash	37.78% ash	2.5% of feed	
88.9% of feed 2.15% sulfur 6.1% ash			5.5% of feed 10.7% sulfur 34.6% ash		

Time 15 minutes
172 strokes per minute
Rate 3250 pounds per hour per sq. ft. screen area

Efficiency, on the basis of float on 1.35 as standard washed coal, 45%

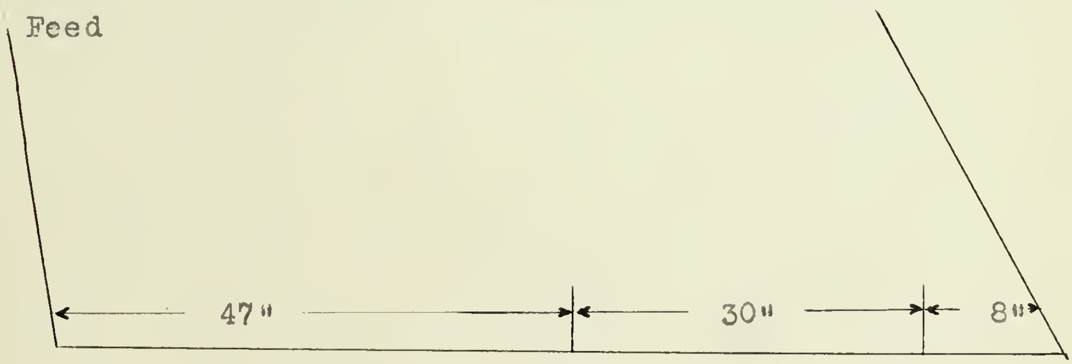
ing what the results would be if only two products were made are arrived at by combining the products as desired and calculating the average ash and sulfur content.

TABLE 37

0" - 3/8" Table Washing Test on the West Virginia Coal

Deister-Overstrom Table

Product	Weight pounds	Per cent of feed	Per cent ash	Per cent sulfur
Raw coal	292	100.0	6.76	2.28
No. 1 Washed coal	97	33.3	4.30	1.65
No. 2 Washed coal	120	41.2	5.11	1.94
No. 3 Coal	53	18.2	10.24	2.84
No. 1 and No. 2 combined	217	74.5	4.77	1.81
No. 1 & No. 2 & No. 3	270	92.7	5.85	2.01
Refuse	15	5.2	30.57	8.90
Loss	7	2.1		



No. 1 Washed Coal No. 2 Coal No. 3

TABLE 38

0" - 1/8" Table Test Spruce River Coal
36 Per cent of 0" - 3/8" Sample
Butchart Table

Product		Weight Grams	% of feed	Cum.[1]	% ash	Cum.[1]	% sulfur	Cum.[1]
Section No.	1	9525	57.30	57.30	6.67	6.67	2.03	2.03
	2	685	4.10	61.40	4.95	6.44	1.82	1.98
	3	846	5.10	66.50	4.47	6.30	1.77	1.97
	4	812	4.90	71.40	4.32	6.15	1.81	1.95
	5	773	4.60	76.00	4.15	6.00	1.80	1.94
	6	708	4.30	80.30	4.23	5.90	1.81	1.94
	7	662	4.00	84.30	4.26	5.80	1.73	1.93
	8	664	4.00	88.30	4.38	5.80	1.79	1.92
	9	717	4.30	92.70	4.95	5.70	1.91	1.92
	10	616	3.70	96.40	7.08	5.80	2.19	1.93
	11	141	.90	97.30	12.50	5.80	3.37	1.95
	12	25	.15	97.45	17.00	5.80	4.50	1.95
	13	16	.10	97.55	17.87	5.90	4.50	1.95
	14	78	.50	98.05	23.02	6.00	5.12	1.97
	15	33	.20	98.25	33.89	6.10	6.80	1.99
	16	36	.22	98.47	37.94	6.20	7.68	1.99
	17	26	.16	98.63	41.91	6.20	8.32	2.00
	18	49	.30	98.83	46.86	6.30	8.94	2.02
	19	198	1.20	100.00	65.74	7.10	16.50	2.20
		16,610	100.00					

[1] Cum. = Cumulative.

See pag 142 Th

Table 7

Specific Gravity Analysis of Hessin Coal

Specific Gravity	Per cent of Sample

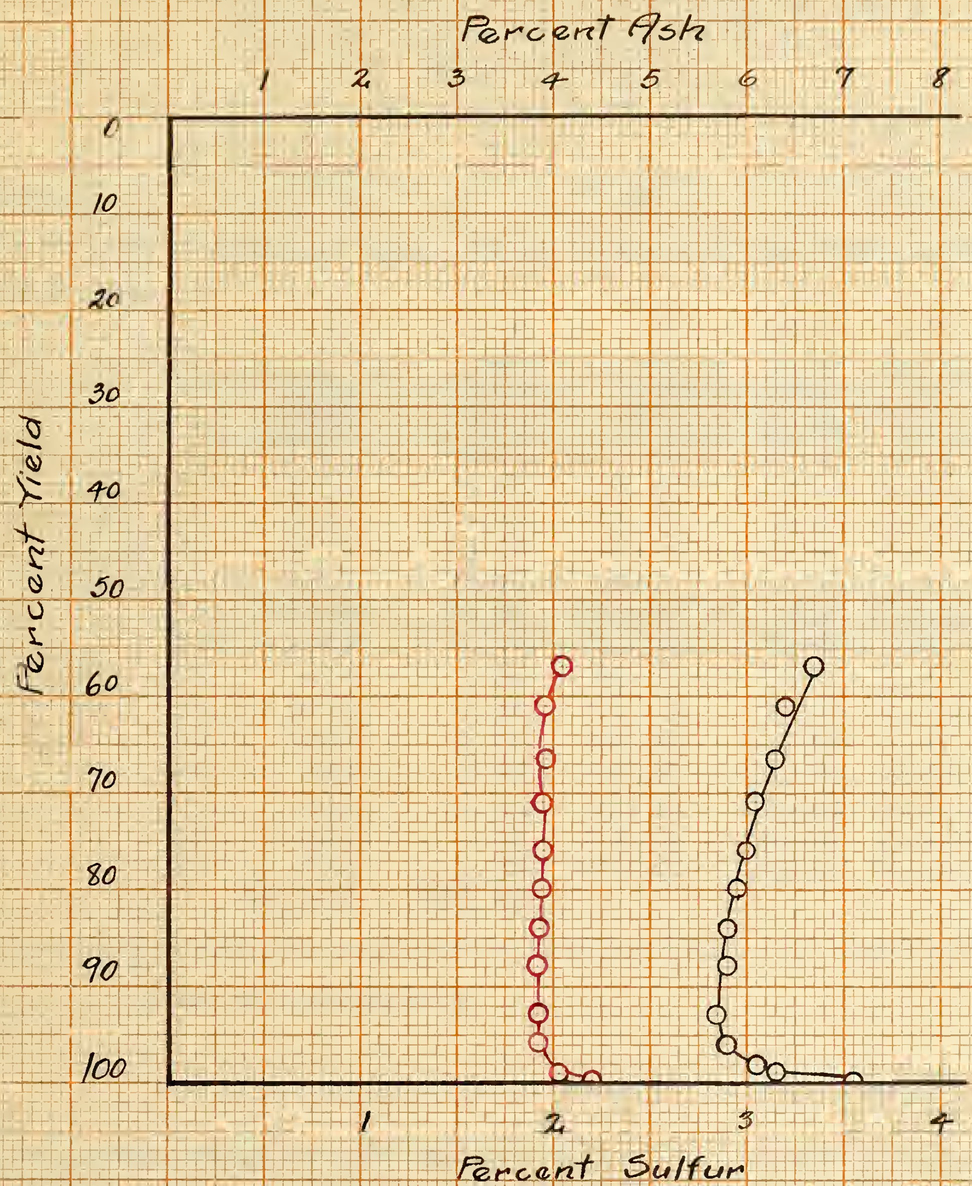


Fig.29 - Yield Curves
West Virginia Coal
0 - 1/8" size
—O— Yield-Sulfur Curve
—O— Yield-Ash Curve

TABLE 39

1/8" - ¼" Table Test Spruce River Coal
41 Per cent of 0" - 3/8" Sample
Butchart Table

Product		Weight Grams	% of feed	Cum.[1]	% ash	Cum.[1]	% sulfur	Cum.[1]
Section No.	1	----	-----	-----	----	----	----	----
	2	23	.06	.06	3.80	3.80	1.17	1.17
	3	175	.45	.51	2.80	2.92	1.26	1.25
	4	834	2.12	2.63	2.60	2.66	1.22	1.22
	5	1891	4.82	7.45	3.10	2.95	1.40	1.34
	6	2596	6.60	14.05	3.00	2.97	1.39	1.37
	7	3310	8.42	22.47	3.00	2.98	1.52	1.42
	8	4144	10.54	33.01	3.10	3.02	1.51	1.45
	9	5378	13.69	46.70	3.50	3.16	1.97	1.60
	10	7637	19.47	66.17	4.00	3.40	2.08	1.75
	11	5030	12.80	78.97	4.90	3.65	2.60	1.88
	12	2489	6.34	85.31	5.80	3.81	2.20	1.90
	13	615	1.56	86.87	7.10	3.87	2.34	1.91
	14	1670	4.25	91.12	9.95	4.15	2.60	1.94
	15	1267	3.23	94.35	14.80	4.52	3.02	1.98
	16	794	2.02	96.37	21.70	4.88	4.49	2.04
	17	440	1.12	97.49	31.30	5.17	6.32	2.09
	18	230	.59	98.08	41.80	5.40	8.10	2.13
	19	779	1.89	100.00	55.60	6.34	17.50	2.41
		39,302	100.06					

[1] Cum. = Cumulative

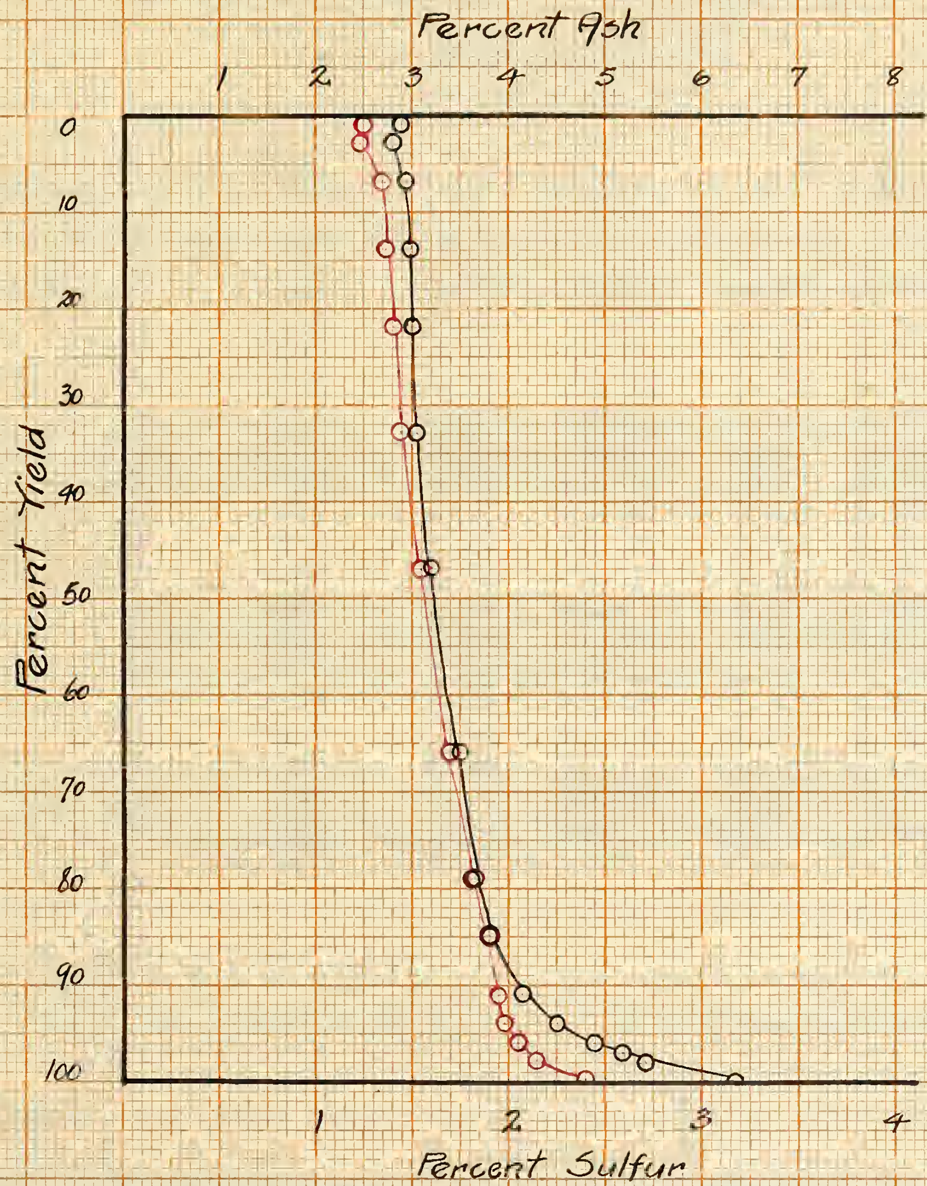


Fig. 30—Yield Curves
West Virginia Coal
1/8"–1/4" size

Yield-Sulfur Curve

Yield-Ash Curve

TABLE 40

¼" - 3/8" Table Test Spruce River Coal
23 Per cent of 0" - 3/8" Sample
Deister-Overstrom Table

Product		Weight Grams	% of feed	Cum.[1]	% ash	Cum.[1]	% sulfur	Cum.[1]
Section No.	1	1125	3.70	3.70	2.80	2.80	1.66	1.66
	2	1188	3.90	7.60	2.95	2.87	1.88	1.77
	3	1465	4.81	12.41	3.20	3.00	1.78	1.77
	4	1252	4.11	16.52	3.40	3.18	1.74	1.76
	5	740	2.43	18.95	3.40	3.20	1.78	1.77
	6	1619	5.31	24.26	3.30	3.22	1.84	1.78
	7	1455	4.77	29.03	3.60	3.28	1.84	1.80
	8	1376	4.52	33.55	3.80	3.36	1.86	1.80
	9	874	2.87	36.42	3.90	3.40	1.92	1.81
	10	1449	4.76	41.18	4.00	3.47	1.92	1.82
	11	1079	3.54	44.72	4.35	3.54	2.07	1.84
	12	1800	5.90	50.62	5.40	3.74	2.04	1.86
	13	2897	9.51	60.13	6.40	4.18	2.26	1.92
	14	5050	16.56	76.69	7.40	4.85	2.52	2.05
	15	5013	16.45	93.14	10.00	5.76	2.86	2.20
	16	1288	4.22	97.36	11.90	6.04	3.66	2.28
	17	201	.66	98.02	18.80	6.10	4.97	2.30
	18	576	1.89	99.91	39.00	6.80	10.10	2.45
		30,447	99.91					

[1]Cum. = Cumulative

These washing experiments with the sink and float tests and chemical analyses demonstrate conclusively that this coal is a difficult one to wash and that the removal of only the free dirt particles in the form of a clean refuse product will result in no very great reduction in sulfur.

The feature of general interest in this investigation is the determination of the characteristics of this coal which render it difficult to improve by washing. That the trouble is not to be overcome by fine crushing, nor by sizing before washing, is indicated by the sink and float tests. The separation in the fine sizes under one-fourth inch is not appreciably better than that secured on the

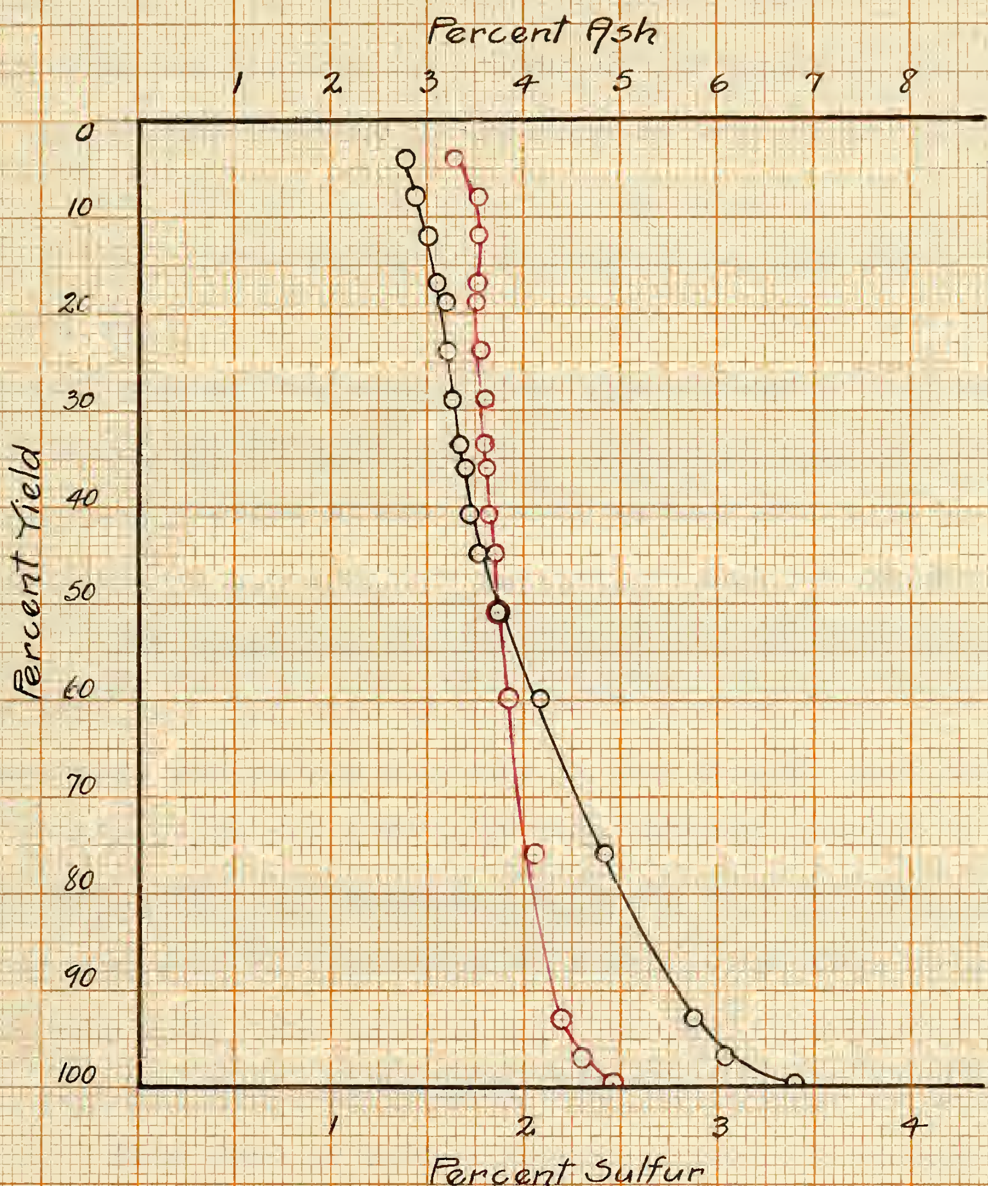


Fig. 31 — Yield Curves
West Virginia Coal
1/4" - 3/8" size

larger sizes from one-fourth inch to three-fourths inch, and the combined results of the two washing tests, where the coal was screened on a one-fourth inch screen before washing, are no better than the results secured in the jigging test on 0" - ¾" unsized coal.

The combined washed coal products from the ¼" - ¾" jig test and the 0" - ¼" table washing test amounted to a total yield of 83 per cent of the feed with an ash content of 5.4 per cent and a sulfur content of 1.95 per cent, while the jig test on 0" - ¾" unsized feed yielded 84 per cent of washed coal with an ash content of 5.3 per cent and a sulfur content of 1.98 per cent.

For comparing the results of the table washing tests on sized feed with the test on 0" - 3/8" unsized feed, the separation between coal and refuse was made in the 0"-1/8" test between samples 11 and 12, in the 1/8" - ¼" test between samples 11 and 12, and in the ¼" - 3/8" test between samples 11 and 12. This gives an average yield of 77.5 per cent of washed coal with an ash content of 5.4 per cent. The test on unsized feed yielded 74.5 per cent of No. 1 plus No. 2 washed coal with an ash content of 4.8 per cent.

This coal is rather unique in that it is high in sulfur, but comparatively low in ash, and that while the sulfur is very refractory, the ash is easily removable. This is an exception to the old rule of thumb that the sulfur follows the ash. The commonest difficulty met with in coal washing is a large percentage of material of intermediate density between 1.30 and 1.60 in specific gravity, consisting largely of bone coal and carbonaceous shale, which forms a middling, or secondary coal too high in ash and sulfur to include in the clean coal and yet too high in combustible to

throw away. However, this is not the source of difficulty with this coal. In fact the sink and float tests show that there is an unusually small percentage of this material present. Visual examination and specific gravity analysis show that there is very little free dirt of high specific gravity in this coal. The sulfur must be present chiefly in some other form than pieces of clean removable pyrite. The different forms of sulfur as they occur in the raw coal are given in Table 41 below, comparing this coal with the Clover Run coal. Pyritic sulfur was determined by the method of Powell with Parr[1], and organic sulfur by difference.

TABLE 41

Forms of Sulfur in Spruce River and Clover Run Coal[1]

Name of coal	Total sulfur %	Organic Sulfur		Fine disseminated pyritic sulfur		Coarse pyritic sulfur	
		%	% of total sulfur	%	% of total sulfur	%	% of total sulfur
Spruce River	2.48	1.01	40.5	0.71	28.6	0.76	30.9
Clover Run	3.48	0.71	20.4	0.50	14.3	2.27	65.3

As shown by this Table an unusually large proportion of the total sulfur is present in the form of organic sulfur, and finely divided pyritic sulfur. These facts and the very low percentage of heavy material in the raw coal indicate that the sulfur is widely distributed and that there are very few concentrations of pyrite in individual pieces sufficient to bring up their specific gravity and

[1]Univ. of Ill. Eng. Exp. Sta. Bull. 111.

make them removable by washing.

32. Indiana No. 3 Coal. A car load sample of this coal was examined at the testing plant of the Deister Concentrator Company. The sample consisted of screenings through a one and one-half inch slot screen. Tests were made with the Deister-Overstrom table on a sample of 5600 pounds crushed to one-half inch maximum size and on a sample of 6600 pounds crushed to one-fourth inch maximum size. Of this 6600 pounds 6400 were tested on the commercial size table at the Deister-Overstrom testing plant and 200 pounds, a carefully taken sample of the total 6600 pounds, was treated on the laboratory table at Urbana.

The conspicuous visible impurities in the raw coal as received consisted of shale bands and clay with very little coarse pyrite. The shale bands were very largely of clean grey shale, although there were also black carbonaceous shale and bone coal particles. The sample used for the 0" - ½" washing test carried 18.7 per cent ash and 3.92 per cent sulfur, the 0" - ¼" sample analyzed 16.5 per cent ash and 3.85 per cent sulfur. The specific gravity analysis of the 0" - ¼" feed is shown in Table 42. This shows it to be about an average coal as far as the proportion of the different specific gravity increments and the distribution of the ash are concerned. The sulfur, however, is shown to be very uniformly distributed through the coal, the lightest fractions being very little lower in sulfur than the heaviest fractions.

TABLE 42

Specific Gravity Analysis Indiana No. 3 Coal
0" - $\frac{1}{4}$" Size

Specific Gravity	Per cent of sample	Per cent ash	Per cent sulfur
Lighter than 1.25	68.0	5.4	3.19
1.25 to 1.30	2.8	8.9	4.12
1.30 to 1.35	5.4	13.4	3.83
1.35 to 1.40	3.7	15.8	3.86
1.40 to 1.45	2.8	20.3	4.10
1.45 to 1.50	1.9	24.9	4.06
1.50 to 1.60	2.6	29.5	3.81
1.60 to 1.80	2.3	42.1	4.12
Heavier than 1.80	10.5	71.5	6.14

TABLE 43

Sink and Float Test Indiana No. 3 Coal
0" - $\frac{1}{2}$" Size; 1.35 Specific Gravity

Product	Per cent of sample	Per cent ash	Per cent sulfur
Float	78.8	6.6	3.27
Sink	21.2	59.1	6.40

This is the coal which was used for comparing the results securable with the laboratory size coal washing table with the work done by the full size machine in commercial operation.

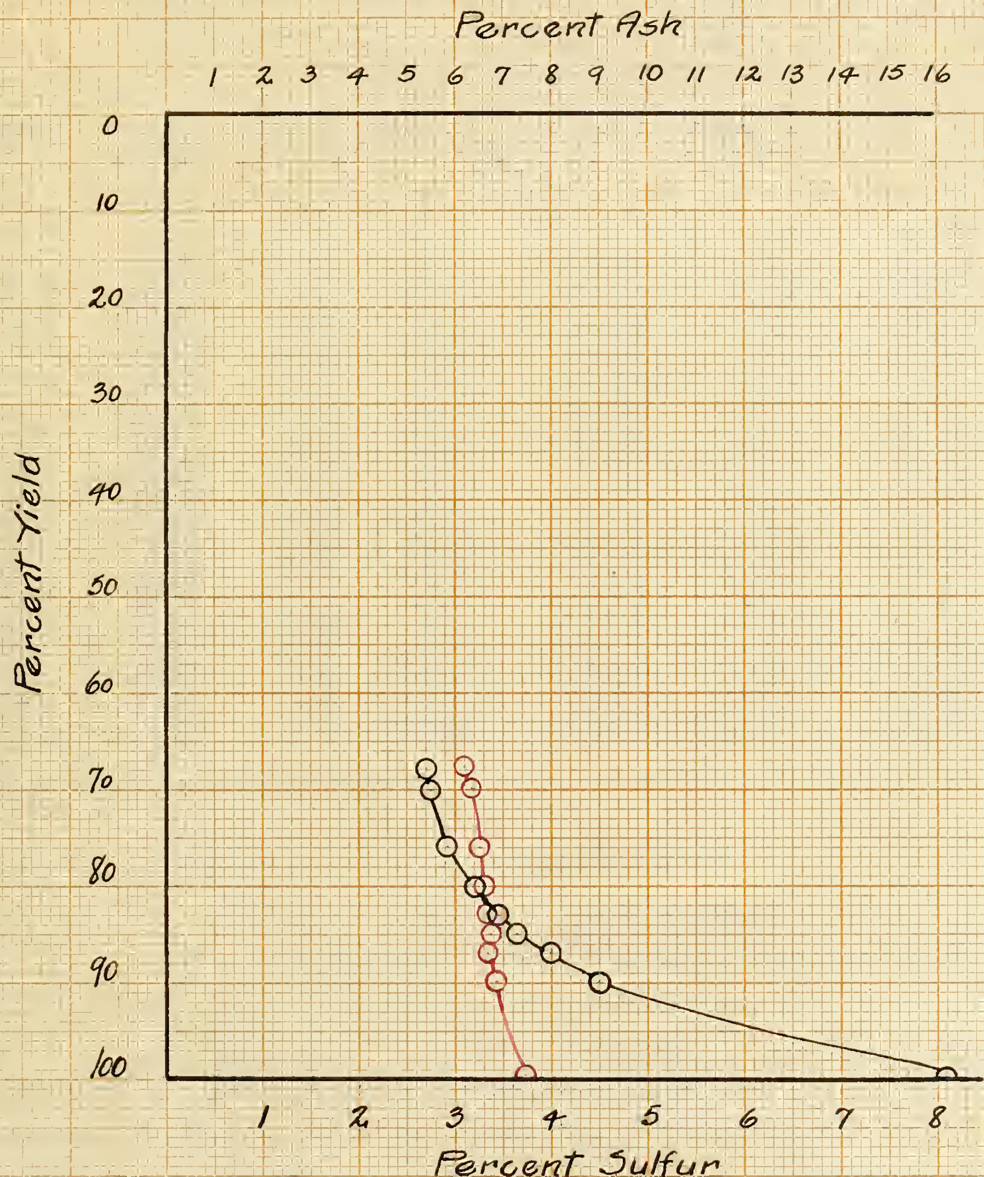


Fig.32—Theoretical Yield Curves
Indiana No. 3 Coal

TABLE 44

Laboratory Table Washing Test on ¼" Indiana Coal
Heads 16.5 per cent ash 3.85 per cent sulfur

Sample	Weight Grams	% of feed	Cum. % of feed	% ash	Cum. % ash	% sulfur	Cum. % sulfur
1	4509	11.6	11.6	10.20	10.20	2.86	2.86
2	1860	4.8	16.4	5.03	8.60	2.95	2.88
3	2015	5.2	21.6	5.14	7.80	3.00	2.90
4	1571	4.1	25.7	5.32	7.40	3.08	2.94
5	1137	2.9	28.6	5.64	7.20	3.13	2.96
6	2107	5.5	34.1	5.77	7.00	3.36	3.04
7	1999	5.2	39.3	6.13	6.90	3.28	3.10
8	2347	6.1	45.4	6.45	6.80	3.41	3.12
9	1863	4.8	50.2	6.97	6.80	3.48	3.13
10	2554	6.6	56.8	6.60	6.75	3.40	3.18
11	3015	7.8	64.6	8.20	6.95	3.50	3.21
12	4720	12.2	76.8	10.85	7.55	3.64	3.27
13	3421	8.9	85.7	18.57	8.70	3.78	3.33
14	3026	7.8	93.5	45.05	11.70	4.11	3.39
15	1798	4.6	98.1	78.00	14.80	8.60	3.64
16	776	2.0	100.0	58.92	15.71	15.65	3.88

TABLE 45

Indiana No. 3 Coal
0" - ½" Washing Test, Deister-Overstrom Table

Product	Wet wt. pounds	% moisture	Dry weight	% of feed	% ash	% sulfur
Raw coal	6180	9.0	5624	100.0	18.73	3.92
Washed coal (Coarse)	5452	18.5	4436	77.0	7.25	3.50
Sludge		(By wt.)	315			
		(By dif.)	283	6.8	34.80	2.66
Refuse	1100	13.6	905	16.2	68.96	5.93

Sample of washed coal including sludge	9.07	3.49
Same by calculation from sludge and bin washed coal	9.00	
Time 27 minutes; rate 6¼ tons per hour	.07	check

The sludge consists of fine material in the water draining from the washed coal as it is elevated to the Draining Bin (34), Fig. 33 , by the dewatering drag conveyor (17). This was sampled where it overflows the washed coal sump 16 to the overflow sump 19.

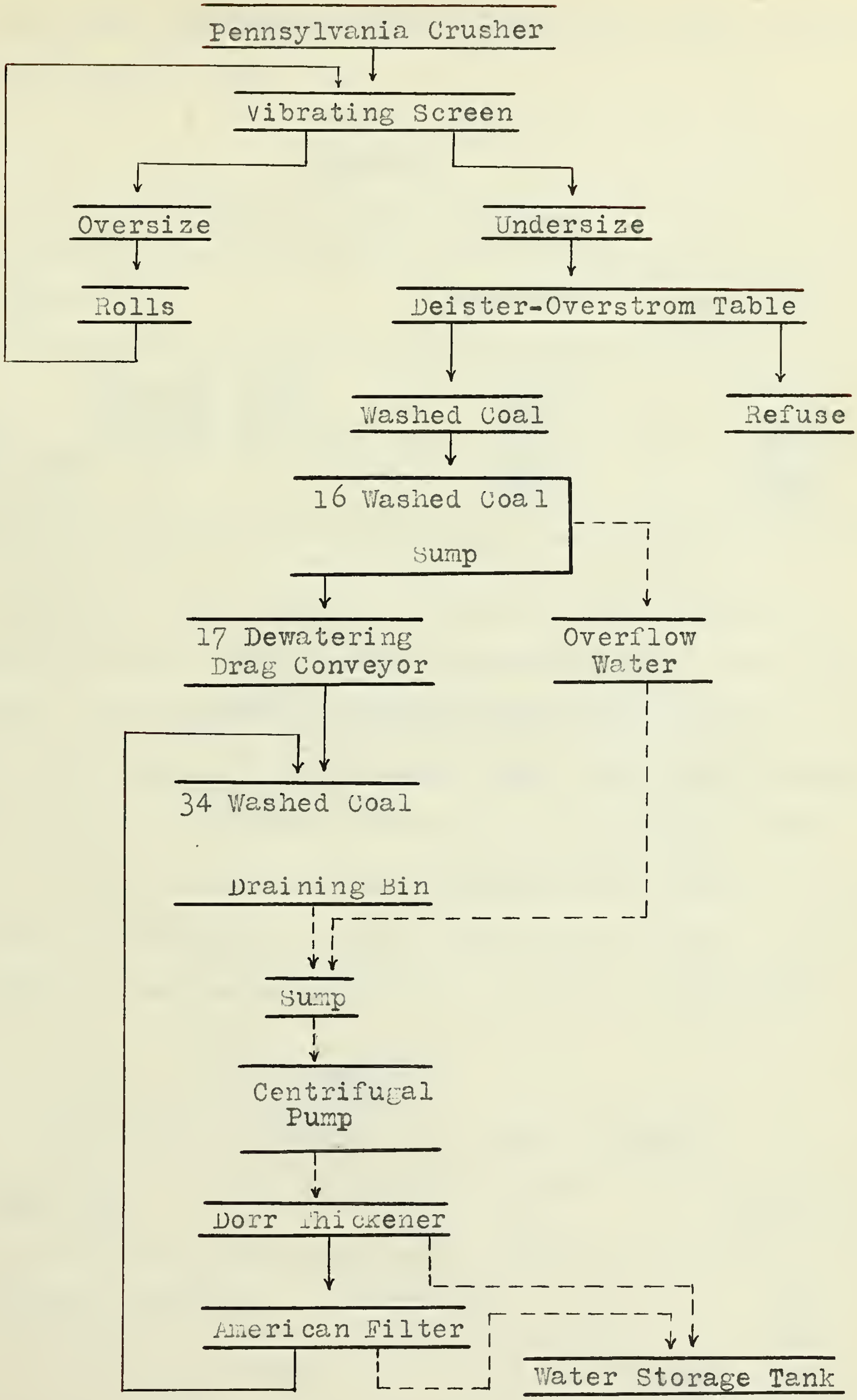


Fig. 33-Flow-Sheet Deister Concentrator Company's Testing Plant

The size of this material in the 0" - ½" test is shown by the screen analysis Table 46.

TABLE 46

Screen Analysis of Sludge

Size		Per cent	Per cent ash
On 1/64"	Through 1/32"	8.2	25.1
On 65 mesh	Through 1/64"	18.2	28.1
On 100 mesh	Through 65 mesh	21.5	28.8
Through 100 mesh		52.1	41.2
Total		100.0	34.8

The loss on the various laboratory tests consists of similar material which overflows the settling cones and tanks in the laboratory. This product varies in amount and composition depending upon the nature of the raw coal used, the type of washer used and the method of handling the coal after washing. The sludge from this particular coal was exceptionally high in ash because the raw coal contained a large proportion of clay. Analysis of sludge samples from two other coals are given in Table 47.

TABLE 47

Ash Content of Washed Coal Sludge Samples

Coal used	Washer used	Ash content
No. 6, Herrin, Illinois.	Campbell	15.5
Ohio, Brier Hill.	Deister-Overstrom	13.5

The sludge is ordinarily higher in ash than the coarse washed coal, but quite often lower in sulfur content.

The two washing tests made on the large table show an ash reduction of 62 per cent and a sulfur reduction of 11 per cent on the 0" - ½" coal and an ash reduction of 58 per cent with a sulfur reduction of 12 per cent on the 0" - ¼" coal. This shows very good work in the removal of ash, but very poor results in sulfur reduction.

This is a coal which is very amenable to washing as far as the ash is concerned because a large proportion of the ash is in the form of clean shale bands, which are easily removed. The sulfur on the other hand is very difficult to remove. Table 48 shows the forms of sulfur in the raw coal and the washer products.

TABLE 48

Forms of Sulfur in Indiana No. 3 Coal

Product	Total sulfur %	Pyritic Sulfur %	Pyritic Sulfur % of total	Fine disseminated Pyritic sulfur %	Organic sulfur %	Organic sulfur % of total
0" - ¼" raw coal	3.85	1.99	52	1.43	1.86	48
0" - ¼" washed coal (coarse)	3.38	1.39	41		1.99	59
0" - ¼" washed coal including sludge	3.32	1.40	42		1.92	58
0" - ½" raw coal	3.92	2.13	54	1.48	1.79	46
0" - ½" washed coal (coarse)	3.50	1.46	41		2.04	59
0" - ½" washed coal including sludge	3.48	1.53	44		1.95	56
Average raw coal	3.88	2.06	53	1.45	1.82	47

Fine disseminated pyritic sulfur is a comparative term which was used in this work to designate the pyritic sulfur occurring in fine particles disseminated through the coal to such an extent that it cannot be removed by any practicable mechanical process. It is

arbitrarily defined[1] here as the pyritic sulfur in the coal which floats on a solution of 1.35 specific gravity out of a representative sample crushed to pass a quarter inch round hole screen. This shows that an unusually large proportion, 53 per cent, of the sulfur in this coal occurs in the organic form, while the Clover Run, Spruce River and Bon Air coals showed only 40.5, 20.4 and 24.0 per cent, respectively, of their total sulfur in organic form. In the Indiana coal the organic sulfur and the fine disseminated pyritic sulfur combined amount 90 per cent of the total sulfur in the raw coal. This eliminates the possibility of removing any appreciable percentage of the sulfur from this coal.

These tests showed a concentration of organic sulfur in the washed coal due to the removal of inorganic mineral matter. This is a condition which might be expected to result in any coal washing operation where an appreciable amount of shale or slate is removed as refuse. This coal, however, was the only one examined with which such a result was actually secured. The raw coal contained a larger proportion of clean shale than any other used in the tests.

Of the two tests the 0" - $\frac{1}{4}$" run showed the larger yield of washed coal by 4.5 per cent. This may be explained as due to the higher percentage of ash in the raw coal used for the 0" - $\frac{1}{2}$" test. As this feed contained 2.2 per cent more ash than the 0" - $\frac{1}{4}$" feed, it is necessary to remove approximately four and a half per

[1]Distribution of the Forms of Sulfur in the Coal Bed, - Ynacey & Fraser, Univ. of Ill. Exp. Sta. Bull. in press.

cent more refuse in order to produce the same quality of washed coal. This indicates that crushing the coal to one-fourth inch maximum size did not result in any better separation on this coal than was secured by washing at 0" - ½" size.

The efficiencies secured in the tests, taking float on a solution of 1.35 specific gravity as standard washed coal, are 85 per cent for the 0" - ½" size and 86 per cent for each of the two tests on 0" - ¼" coal.

CHAPTER VIII

CONCLUSIONS

33. Sulfur Reduction. The washing tests showed reductions of total sulfur content in the No. 1 washed coal product varying from a minimum of 11 per cent with the Indiana coal to a maximum of 63 per cent with the Clover Run coal washed on the concentrating table. Tests on the five coals examined showed great variation in sulfur reduction. Table 49 gives a summary of the results secured on the different coals by the different methods of washing used.

The Clover Run coal which showed the largest reduction in sulfur contained the smallest proportion of its sulfur in the organic form. In the size at which the maximum sulfur reduction was secured it contained a comparatively large amount, 6.8 per cent, of material heavier than 1.80 specific gravity and analyzing 23 per cent sulfur, while the proportion of natural middling between 1.35 and 1.60 in specific gravity amounted to only 12.6 per cent.

The Indiana No. 3 coal which was the most difficult of the five to wash as regards sulfur removal, contained 53 per cent of its sulfur in the organic or combined form; while the Bon Air coal also difficult to desulphurize, though comparatively low in organic sulfur, contained most of its pyrite in the form of finely divided particles disseminated through the coal. As received at the laboratory, this coal, although it contained 4.87 per cent sulfur and 15.0 per cent ash, showed very little free visible impurity. The sink and float tests show that the lightest material separated out, namely, float on solution of 1.26 specific gravity amounting

Table 49

Sulfur Reductions in the Washing Tests

Coal Used	Machine Used	Raw Coal Size	Raw Coal Per cent Sulfur	No. 1 Washed Coal Yield	No. 1 Washed Coal Per cent Sulfur	No. 1 Washed Coal Per cent Reduction	Washed + Secondary Coal Yield	Washed + Secondary Coal Per cent Sulfur	Washed + Secondary Coal Per cent Reduction
1. Herrin	Jig	1/4"-1"	2.70	89.5	1.89	30			
2. Herrin	Table	0"-1/4"	2.70	78.5	1.85	32	86.3	1.90	30
3. Bon Air	Jig	0"-3/8"	4.87	86.9	3.80	22	86.9	3.80	22
4. Bon Air	Table	0"-3/8"	4.87	42.9	3.07	37	76.9	3.48	29
5. Bon Air	Table	0"-3/8"	4.87	54.6	3.02	38	86.6	3.82	22
6. Clover Run	Jig	0"-1"	3.48	72.0	2.02	42	88.5	2.72	22
7. Clover Run	Jig	1/4"-1"	3.50	85.0	2.34	33	94.0	2.55	27
8. Clover Run	Table	0"-1/4"	3.56	63.0	1.31	63	89.0	1.72	52
9. (7) (8)	Jig & Table	0"-1"	3.53	74.5	1.88	47			
10. Clover Run	Table	0"-3/8"	3.48	74.7	1.53	56	86.5	1.89	46
11. Spruce River	Jig	0"-3/4"	2.48	84.0	1.98	20	91.4	2.06	17
12. Spruce River	Jig	1/4"-3/4"	2.56	83.5	2.04	20	88.9	2.15	16
13. Spruce River	Table	0"-1/4"	2.31	56.5	1.84	20	87.0	1.95	15
14. (12) (13)	Jig & Table	0"-3/4"	2.49	76.0	2.00	20	88.2	2.10	16
15. Spruce River	Table	0"-3/8"	2.28	33.3	1.65	33	92.7	2.01	12
16. Indiana No. 3	Table	0"-1/2"	3.92	77.0	3.50	12	83.8	3.49	12
17. Indiana No. 3	Table	0"-1/4"	3.85	81.5	3.38	11	87.1	3.32	12
18. Indiana No. 3	Table	0"-1/4"	3.85	76.8	3.27	15	85.7	3.33	12

to only 16.3 per cent of the original raw coal, contained 1.28 per cent of pyritic sulfur, and 7.8 per cent ash. This shows that a part of the pyrite and the ash is distributed through the lightest coal.

The West Virginia coal from which it was also difficult to remove the sulfur, contained, like the Indiana coal, a large part (40.5 per cent) of its sulfur in the organic form.

Table 50 shows the forms of sulfur in the five coals examined and some other well known Eastern and Central District coals.

Table 50

Pyritic and Organic Sulfur in Various Coals

Name of coal	Total sulfur Per cent	Pyritic Sulfur		Fine disseminated pyritic sulfur		Organic sulfur	
		Per cent	Per cent of total sulfur	Per cent	Per cent of total sulfur	Per cent	Per cent of total
Herrin	2.70	1.80	67.0	.92	34.0	0.80	33.0
Bon Air	4.87	3.70	76.0	1.83	37.6	1.17	24.0
Clover Run	3.48	2.77	79.6	.50	14.3	.71	20.4
West Virginia	2.48	1.47	59.5	.71	28.6	1.01	40.5
Indiana No. 3	3.88	2.06	53.0	1.45	47.0	1.82	47.0
Middlefork (Benton, Illinois)	8.29	1.99	60.5	.77	23.4	1.30	39.5
No. 12 W. Kentucky	1.48	0.70	47.4	0.34	23.6	0.78	52.6
No. 9 West Ky.	3.46	1.65	47.5	0.73	21.1	1.87	52.5
No. 4 Indiana (Vandalia)	1.66	0.89	53.6			0.77	46.4
Pond Creek Pike Co. Kentucky	0.46	0.13	28.0			0.33	72.0
Elkhorn Letcher Co. Ky.	0.68	0.13	25.0			0.51	75.0
Pocahontas	0.55	0.08	16.3			0.46	83.7

Sulfate sulfur is omitted from this table. As in all the coals examined it amounted to less than 0.1 per cent, it was considered negligible in amount. In Eastern and Central District coals sulfate sulfur is ordinarily present in freshly mined samples only in very small percentages.

TABLE 51

Forms of Sulfur in Raw Coal and Washer Products

Coal	Product	Total sulfur	Pyritic sulfur	Organic sulfur
Bon Air[1]	Raw coal	4.87	3.59	1.17
	Table washed coal	3.02	1.84	1.18
	Table refuse	17.74	16.77	0.97
	Float on 1.27	2.80	1.50	1.30
	Jig washed coal	3.80	2.61	1.19
Herrin[2]	Raw coal	1.83	1.04	0.79
	No. 1 washed	1.81	1.05	0.76
	No. 2 washed	1.56	0.78	0.78
	No. 3 washed	1.57	0.82	0.75
	No. 4 washed	1.57	.81	0.76
	No. 5 washed	2.33	1.57	0.76
Indiana No. 3	Raw coal	3.87	2.06	1.81
	½" washed coal	3.47	1.53	1.94
	¼" washed coal	3.42	1.40	2.02
Illinois No. 6[3]	Raw coal	3.29	1.99	1.30
	Washed coal	2.25	0.92	1.33

These figures show not only that there is no reduction in organic sulfur content by washing, but that in some cases there is a larger percentage of organic sulfur in the washed coal than in the raw coal. This is due to the concentration of organic matter in the clean coal by the removal of mineral matter in the refuse. This effect is most apparent in the tests on the Indiana coal, which contained a large proportion of clean shale.

This limits the removable sulfur of coal to pyrite, segregated in particles large enough to concentrate by specific gravity, and gypsum, in such coals as contain gypsum in appreciable

[1]Some Factors that effect the Washability of a Coal, Fraser & Yancey, A. I. M. E. Bull. 153, p. 1817.

[2]Samples taken at the Campbell Table Washery of the Big Muddy Coal & Iron Co.; Nos. 1,2,3,4, and 5 refer to standard sizes of washed coal.

[3]Average of a number of samples taken at the Washery of the U. S. Fuel Co., Benton, Illinois.

[illegible]

These figures indicate that the difficulty in removing the sulfur from the coals which have been designated as non-washable, namely, the Bon Air, West Virginia and Indiana No. 3 coal, is due to the presence of large percentages of organic sulfur or of fine disseminated pyritic sulfur or more commonly of both in the raw coal.

It has generally been taken for granted that the organic sulfur of coal is not reduced by washing.[1] The results secured in the experimental work of this study substantiate this assumption. Results of the determination of the forms of sulfur in the raw coal and washer products on some of the coals used are given in Table 51.

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[1]Bituminous Coal Washing, L. A . Harding and G. R. Delamater; Mines and Minerals, Vol. 25, p. 451; Chemical Control of Coal Washers, Bolling; Eng. & Min. Journ., Aug. 29, 1908; Coal Washing in Illinois, F. C. Lincoln; Eng. Exp. Sta. Bull.,69, p. 12.

quantities. Table 52 gives the per cent reduction in pyrite sulfur secured on the coals tested.

TABLE 52

Per cent Reduction in Pyritic Sulfur

Coal used	Machine Used	Reduction in pyritic sulfur % Maximum secured	Maximum secured with a practicable yield of washed coal	Yield of washed coal %
Herrin	Table	44.0	41	91.6
	Jig	39.0	39	89.5
Bon Air	Table	51.5	29	86.6
	Jig	28.0	28	86.9
Clover Run	Table	78.0	64	89.0
	Jig	53.0	41	85.0
West Virginia	Table	50.0	45	75.0
	Jig	34.0	30	91.4
Middlefork	Jigs	52.0	52	85.0
	Tables	59.0	59	
Indiana No. 3	Tables	38.0	38	85.4
Average for tables		53.0	46	
Average for jigs		40.0	38	

In drawing conclusions from these figues it is essential to take into account the fact that most of the coals tested were submitted for examination largely because they presented exceptional difficulties to sulfur reduction. Taking this into consideration, it seems safe to expect that, with most coals, 50 per cent of the pyritic sulfur may be removed by washing, although as illustrated by the Indiana coal, there are exceptional cases, where a large proportion of the pyritic sulfur is fine and disseminated through the coal.

34. Ash Reduction. The reductions in ash content secured in the washing tests are shown in Table 53. The greatest reduction in ash, 62 per cent, was made on the Indiana No. 3 coal, which con-

Table 53

Ash Reductions in the Washing Tests

Coal Used	Machine Used	Raw Coal Size	Raw Coal Ash per cent	No. 1 Washed Coal Yield Per cent	No. 1 Washed Coal Ash Per cent	No. 1 Washed Coal Reduction Per cent	Washed + Secondary Coal Yield Per cent	Washed + Secondary Coal Ash Per cent	Washed + Secondary Coal Reduction Per cent
1. Herrin	Jig	1/4"-1"	11.0	89.5	7.7	29			
2. Herrin	Table	0"-1/4"	14.2	78.5	7.2	49	86.3	8.1	43
3. Bon Air	Jig	0"-3/8"	15.1	86.9	13.3	12	86.9	13.3	12
4. Bon Air	Table	0"-3/8"	15.1	42.9	11.4	24			
5. Bon Air	Table	0"-3/8"	15.1	54.6	11.3	25			
6. Clover Run	Jig	0"-1"	12.8	72.0	9.8	23.5	88.5	11.5	10
7. Clover Run	Jig	1/4"-1"	14.1	85.0	11.4	19.0	94.0	11.9	16
8. Clover Run	Table	0"-1/4"	10.4	63.0	5.3	49.5	89.0	7.2	31
9. (7) (8)	Jig & Table	0"-1"	12.2	75.0	8.9	25.0	92.0	10.7	13
10. Clover Run	Table	0"-3/8"	12.8	74.7	7.9	38.0	86.5	9.21	28
11. Spruce River	Jig	0"-3/4"	6.8	84.0	5.3	22.0	91.4	5.9	13
12. Spruce River	Jig	1/4"-3/4"	6.9	83.5	5.6	19.5	88.9	6.1	11
13. Spruce River	Table	0"-1/4"	6.6	56.5	4.7	28.5	87.0	5.8	12
14. (12) (13)	Jig & Table	0"-3/4"	6.8	76.0	5.4	21.2	88.2	6.0	12
15. Spruce River	Table	0"-3/8"	6.7	33.3	4.3	36.4	92.7	5.8	13
16. Indiana No. 3	Table	0"-1/2"	18.7	77.0	7.2	62.0	83.8	9.0	52
17. Indiana No. 3	Table	0"-1/4"	16.5	81.5	6.9	58.0	87.1	8.5	48
18. Indiana No. 3	Lab. Table	0"-1/4"	16.5				85.7	8.7	48

1. Coarse washed coal
2. Coarse washed coal and sludge

tained a large proportion of heavy clean shale. The smallest reduction was on the Bon Air coal. This coal, as the analysis of the raw coal shows, contained a large percentage of ash, but it was largely in the form of very thin bands of shale interbedded with the coal and the disseminated ash of bone coal and light carbonaceous shale. The effect of this is shown in the specific gravity analysis of the raw coal. Even when crushed to one-fourth inch maximum size, many particles are part dirt and part coal. Only 60 per cent floats on a solution of 1.30 specific gravity and only 4.1 per cent is heavier than 1.60. The remainder 35.9 per cent is intermediate in density, and consists of middling coal particles, high in ash. Fig. 3, in Chapter III, shows the specific gravity analysis of the Bon Air coal compared with the Herrin coal which is much more amenable to washing. The Bon Air coal contains 36.1 per cent of material between 1.30 and 1.45 in specific gravity, while the fraction between these densities in the Herrin coal amounts to only 15.5 per cent of the total.

Another factor which affects the result of washing on the Bon Air coal is the high ash content of the lightest coal, floating on 1.30 specific gravity solution. This analyzed 10.1 per cent, while the corresponding increment of the Herrin coal contained 4.64 per cent, of the Indiana coal 5.4 per cent, and of the Clover Run coal 5.8 per cent. The Bon Air coal is a typical boney coal consisting mainly of dull coal or atritus, bone coal and light carbonaceous shale. As received, the coal sample showed very few bright coal particles.

The Bon Air coal was the only coal of its type examined during this study. Such coals are common in the Western and

Alaskan fields. Tables 54 and 55 show specific gravity analysis of two such coals which contain even larger percentages of middling. In washing these coals, the separation between washed coal and refuse has to be made at a much higher specific gravity than in the average Eastern or Central District coal and a higher ash fuel must be acceptable.

TABLE 54

Specific Gravity Analysis of a Washington Coal[1]
Number 2 Bed 0" - 2½" Size

Specific Gravity	Per cent of raw coal	Per cent ash
Float on 1.40	38.9	11.9
1.40 to 1.50	14.4	26.2
1.50 to 1.70	16.7	39.2
Sink on 1.70	29.8	72.6
Total sample	100.0	36.6
	Same 0" - 3/8" Screenings	
Float on 1.40	56.3	8.8
1.40 to 1.50	8.1	25.2
1.50 to 1.70	14.4	36.2
Sink on 1.70	21.2	72.3
Total Sample	100.0	27.5

The analysis of the Washington coal shows it to be a mixture of clean coal, bone coal, and shale with only a small proportion of free particles of clean coal in the 0" - 2½" size. The 0" - 3/8" size shows a much larger proportion of material lighter than 1.40, but this is not entirely due to a more complete separation of dirt particles from coal particles at the finer size, as

[1]Experimental work by E. R. McMillan, Northwest Station, U. S. Bureau of Mines.

the average ash content of the entire sample is much lower than in the 0" - 2½" unsized coal.

The coal is washed at 0" - 2½" size on Blair jigs yielding 60 per cent of washed coal with an ash content of 19.1 per cent and 40 per cent refuse carrying 59.1 per cent.

TABLE 55

Specific Gravity Analysis of a New Mexico Coal

Specific Gravity	Per cent of sample	Per cent ash
Float on 1.25	0.39	4.4
1.25 to 1.30	23.10	7.4
1.30 to 1.35	29.39	11.4
1.35 to 1.40	11.55	16.9
1.40 to 1.45	5.15	21.3
1.45 to 1.50	5.19	25.8
1.50 to 1.55	6.81	31.8
1.55 to 1.60	3.22	36.4
1.60 to 1.65	3.77	40.1
1.65 to 1.70	2.59	44.7
1.70 to 1.75	1.98	46.1
1.75 to 1.80	1.17	51.9
Sink on 1.80	5.69	65.5

It is worthy of note that of the five coals examined the Indiana coal, which gave the best results in the way of ash reduction, showed the lowest reduction in sulfur, and that the Clover Run coal on which the greatest reduction in sulfur was secured showed a comparatively small improvement in ash content. This is contrary to the general statement sometimes made that the sulfur follows the ash.

On the Indiana coal tests, the very fine washed coal, designated as sludge in the reports, contained a very large percentage of ash, 34.8 in the 0" - ½" test, and 32.3 in the 0" - ¼"

test. This indicates that the fire clay was not separated from the coal, but due to the very fine size of the particles it was carried over the washed coal discharge side of the table with the light coal. This happens to a greater or less degree in any coal washing operation, but was most noticeable in the Indiana coal tests because of the exceptionally large percentage of clay in the raw coal. This effect is explained by the theory of settling velocities, Chapter III, as due to the fact that the ratio of sizes in the feed exceeds the ratio of sizes of equal settling particles of coal and shale to such an extent that the smallest particles of the heavy mineral settle at the same rate as the largest particles of the light mineral. While it is well known that a ratio of sizes greatly exceeding this theoretical settling ratio may be handled together efficiently, it is often observed[1] that the very fine material in the feed to a coal washer is not cleaned.

At the Middlefork washer when the coal was washed at about 0" - $1\frac{1}{2}$" size, the fine material which was not appreciably benefited by the operation, amounted to from 8 to 10 per cent of the raw coal fed.

Due to the disintegration of friable shale and clay particles in the washer the fine washed coal is sometimes higher in ash content than the corresponding size in the feed. This has evidently taken place in the Indiana coal tests. The fine material may be partially separated from the coarse washed coal by wet screening or by the use of a perforated bucket elevator or a de-

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[1]Coal Washing, Coal Wendell. An article to be published in Coal Age; Coal Washing, Ernst Prochaska.

watering conveyor to move the washed coal from the collecting sump to the storage bins. It is usually not high enough in ash to be discarded as refuse, but may be cleaned by rewashing separately, or may be used separately as a secondary coal.

35. Disposal by the Washer of Particles of Various Specific Gravities. As already pointed out, the washability of a coal depends very largely upon the method of occurrence of the impurities. If the excess ash and sulfur are concentrated in a comparatively few particles of high specific gravity, the coal lends itself well to the washing process, while if the impurities are distributed through a large proportion of lighter particles the coal is difficult to wash. Specific gravity analyses of raw coal samples and samples of the resulting washed coal show what kind of particles go into the washed coal and how much of each heavy specific gravity increment in the raw coal is removed. Table 56 gives these figures for each of the coals examined.

TABLE 56

Specific Gravity Analysis of Raw and Washed Coals

	Machine used Table Coal used Herrin Raw	Machine used Table Coal used Herrin No. 1 Washed	Table Clover Run Raw	Table Clover Run No. 1 Washed	Table West Virginia Raw	Table West Virginia No. 1 Washed
Per cent sink in 1.80	7.52	0.57	6.8	0.4	2.0	0.4
1.60 to 1.80	2.13	0.34	2.7	1.2	1.3	0.6
1.50 to 1.60	1.12	0.54	3.2	1.6	0.9	0.5
1.45 to 1.60	0.39	0.27	2.0	2.8	0.6	0.4
1.40 to 1.45	1.82	0.88	3.4	5.1	0.9	1.0
1.35 to 1.40	4.93	3.70	3.7	3.6	1.0	1.2
1.30 to 1.35	8.74	8.30	78.2	85.3	9.1	5.2
1.25 to 1.30	73.35	85.50			33.0	31.8
Float on 1.25					51.2	58.9

	Machine used Table Coal used Bon Air Raw	Machine used Table Coal used Bon Air No. 1 Washed	Table Indiana 0" - ¼" Raw	Table Indiana 0" - ¼" No. 1 Washed
Per cent sink in 1.80	3.0	0.40	10.5	0.4
1.60 to 1.80	1.1	0.50	2.3	0.2
1.50 to 1.60	2.1	0.80	2.6	1.5
1.45 to 1.50	1.8	0.78	1.9	2.5
1.40 to 1.45	3.8	3.76	2.8	3.0
1.35 to 1.40	11.8	11.80	3.7	3.6
1.30 to 1.35	20.5	5.50	5.4	5.9
1.25 to 1.30	39.6	57.00	2.8	3.6
Float on 1.25	13.3	19.40	68.0	79.3

	Machine used Blair Jig Coal used Washington coal 0" - 2½" Raw	Machine used Blair Jig Coal used Washington coal 0" - 2½" Washed
Sink in 1.70	29.8	3.4
1.50 to 1.70	16.9	11.2
1.40 to 1.50	14.4	24.5
Float on 1.40	38.9	60.9

These figures for washed coal in each case represent the cleanest coal secured. In some of the tests this product, designated No. 1 coal, amounted to too small a percentage of the raw coal for the production of a washed coal of that quality to be commercially feasible, unless a certain tonnage of secondary coal of considerably higher ash content can be disposed of.

In the table tests almost all the material heavier than 1.80 specific gravity was removed in each case, leaving a residual portion amounting to from 0.4 to 0.5 per cent of the washed coal. Generally speaking, there was a small percentage of each of the heavy increments above 1.45 in specific gravity in the washed coal than in the raw coal. The percentage of middling particles lighter than 1.45 was generally no lower in the washed coal than in the raw coal.

On the Washington coal, washed at 0" - 2½" size with the Blair Jig, the washed coal contained 3.4 per cent of material heavier than 1.70 in specific gravity and a little smaller percentage of middling, from 1.50 to 1.70, than the raw coal. There was a concentration of particles lighter than 1.50 in the clean coal. Since this coal is so radically different from the five coals examined at Urbana, it is impossible to make any comparison in the work of the machines. The figures on the Washington coal merely illustrate the fact that the washing of such a coal presents an entirely different problem from that of the Eastern District coals. The object aimed at is to make a separation at about 1.50 specific gravity and produce a low grade fuel from an otherwise valueless material.

Table 57 shows the distribution made by the washing table of the particles of various specific gravities in the raw coal. The figures given were secured in the 0" - ¼" test on the Indiana coal using the commerical size Deister-Overstrom table. An unavoidable error was incurred in making the specific gravity tests on the washed coal because of the loss of very fine slime in the heavy solution used. For this reason the value given for sink in 1.80 specific gravity solution is too low.

TABLE 57

Specific Gravity Analyses of Products of the 0" - ¼" Washing Test on Indiana No. 3 Coal

Specific Gravity	Washed coal		Refuse		Raw coal	
	Per cent	Per cent of raw coal	Per cent	Per cent of raw coal	By analysis	Washed coal plus refuse
Lighter than 1.25	79.3	68.9	----	----	68.0	68.9
1.25 to 1.30	3.6	3.1	.2	----	2.8	3.1
1.30 to 1.35	5.9	5.1	.1	----	5.4	5.1
1.35 to 1.40	3.6	3.1	.2	----	3.7	3.1
1.40 to 1.45	3.0	2.6	4.2	0.5	2.8	3.1
1.45 to 1.50	2.5	2.1	2.4	0.3	1.9	2.4
1.50 to 1.60	1.5	1.3	5.0	0.7	2.6	2.0
1.60 to 1.80	0.2	0.2	16.0	2.0	2.3	2.2
Heavier than 1.80	0.4	0.4	72.0	9.3	10.5	9.7

Fig. 34 shows graphically the distribution made by the laboratory table of the various kinds of particles as regards both specific gravity and size. For this work a sample of the West Virginia coal at 0" - 3/8" size was used. The data was secured by making a specific gravity analysis on each of the four products, No. 1 coal, No. 2 coal, No. 3 coal and refuse and screening each

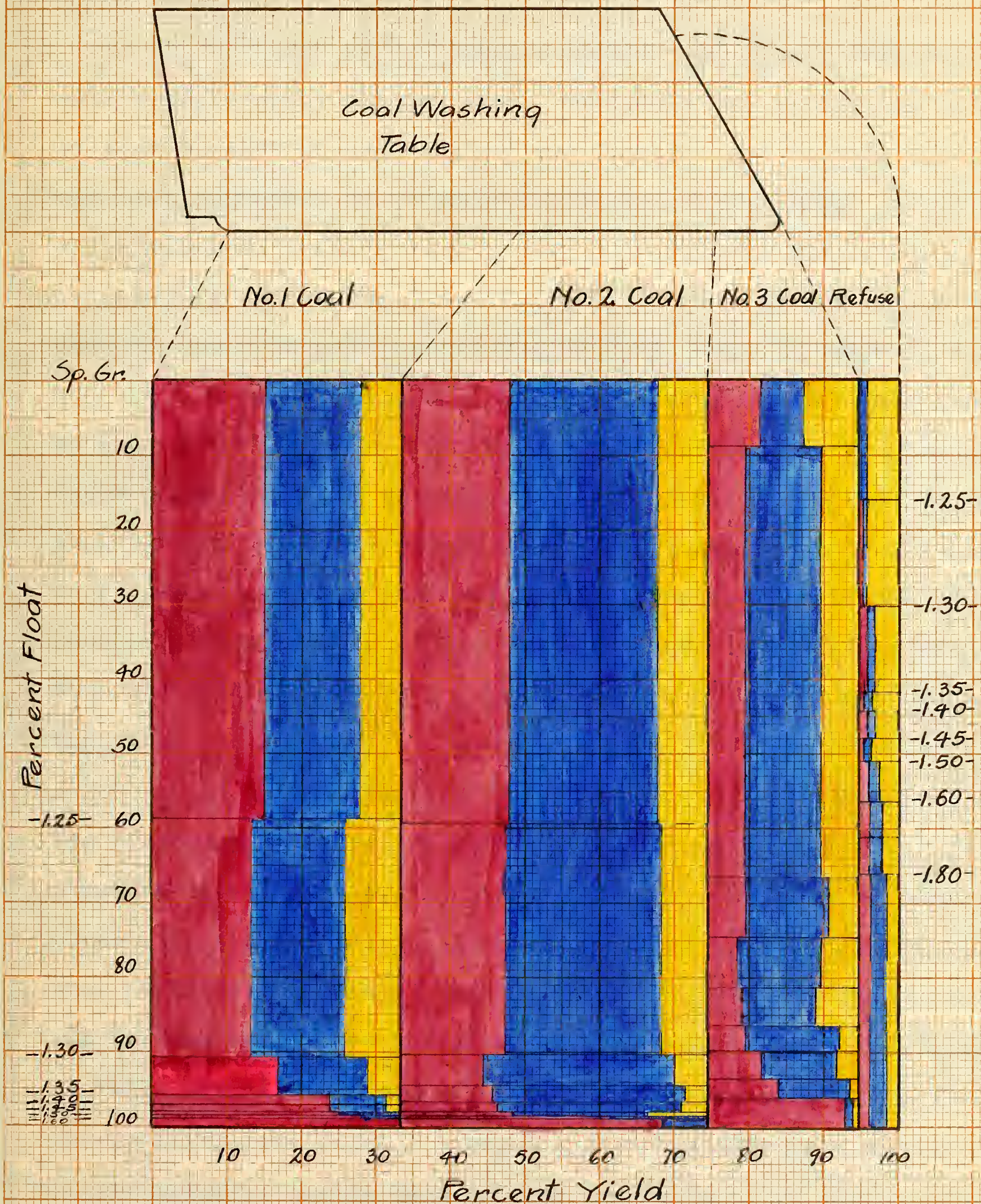

Fig. 33 — The Distribution made by the Table of Particles of Various Sizes and Specific Gravities

0 - 1/8″   1/8″ - 1/4″   1/4″ - 3/8″

specific gravity fraction into three sizes: 0" - 1/8", 1/8" - ¼", and ¼" - 3/8".

The area of the large square in the figure represents the entire coal sample 100 per cent. Therefore the percentage relation of each product to the original raw material and to each other product is represented by the relative areas on the graph. In addition, the cumulative yield of washed coal securable by combining products may be read from the horizontal scale and the cumulative percentages of float in each product may be read from the vertical scale.

This graph shows (in the upper right hand corner) that the loss of good coal, float on 1.25, 1.30, and 1.35 specific gravity solutions consists almost entirely of large particles, while the heavy particles in the No. 1 washed coal are all smaller than one-eighth inch, as shown in the lower left hand corner. This is due to fine clay particles carried over with the washed coal near the head motion end of the table in the section marked No. 1 in the drawing Fig. 24.

In all the tests in which a natural feed[1] was treated on the tables and the special equipment for dividing the product into a number of separate parts was used, a higher ash content was secured in the sample discharged into this No. 1 section than in several sections following. This was especially marked in the test on the Indiana coal where the product from section No. 1 amounting to 11.6 per cent of the feed carried 10.2 per cent ash, while the material going over between this section and a point about half way to the middling corner carried only from 5 to 6 per cent.

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[1]Containing all sizes from a given maximum down to 0.

36. Efficiencies. The formula devised for calculating efficiencies,

$$\text{Efficiency} = \frac{\text{Actual yield x actual ash reduction}}{\text{Standard yield}^{1} \text{ x standard ash reduction}}$$

was applied in all the tests made and was found fairly satisfactory. For comparing the results secured with different machines on the same coal, the efficiency figures give an indication of the relative advantage of the machines used for treating that particular coal, but when the operations to be compared are on radically different coals, the comparison of the machines by the efficiency figures is uncertain, because the completeness of the separation secured depends upon the nature of the coal as well as upon the process used. The efficiency, as calculated, depends upon the proportion of heavy material taken out as a percentage of the total amount of heavy material occurring in the raw coal. The figures of Table 57 indicate that the average percentage of sink particles retained in the washed coal is a more or less constant minimum rather than a certain proportion of the amount occurring in the original raw coal. For this reason a coal like the Indiana No. 3, which contains a large proportion of heavy removable refuse will show a higher efficiency, as calculated, than such a coal as the West Virginia sample which contained only a very small percentage of sink particles. This may also explain the high efficiency of the jig operating on the Washington coal which shows, by calculation

[1] Yield by sink and float test on the solution used as the permissible bath.

from the above formula, an efficiency of 97 per cent while the washed coal contains 3.4 per cent of the heaviest material as compared with 0.4 to 0.5 per cent for all the other coals reported. Table 58 shows the efficiencies secured in the tests.

TABLE 58

Efficiency Figures For the Washing Tests

Coal used	Size	Machine used	Per cent ash			Yield		Efficiency
			Raw coal	Washed coal	Float coal	Float coal	Washed coal	
Herrin	¼" - 1"	Jig	11.0	7.7	5.6	82.0	89.5	67
Herrin	0" - ¼"	Table	14.2	7.2	5.4	82.0	78.5	76
Bon Air	0" - 3/8"	Jig	15.1	13.1	12.1	92.0	86.6	56
Bon Air	0" - 3/8"	Table	15.1	13.3	12.1	92.0	86.6	56
Clover Run	0" - 1"	Jig	12.8	9.8	5.4	74.5	78.0	44
Clover Run	¼" - 1"	Jig	14.1	11.4	6.2	65.0	85.0	48
Clover Run	0" - ¼"	Table	10.4	6.2	4.3	85.1	82.5	74
Clover Run	0" - 3/8"	Table	12.8	7.9			74.7	80
West Virginia	0" - ¾"	Jig	6.8	5.3	4.0	91.2	84.0	48
West Virginia	¼" - ¾"	Jig	6.9	5.5	4.0	90.0	83.5	45
West Virginia	0" - 3/8"	Table	6.8	4.8	3.8	93.3	74.5	54
Indiana No. 3	0" - ¼"	Table	18.7	9.0			83.8	85
Indiana No. 3	0" - ½"	Table	16.5	8.5			87.1	86

Considering each coal separately, washing on the table at fine size showed, as a rule, a slightly higher efficiency than jigging at larger size.

The low efficiencies secured in the jigging tests may be due, in a measure, to the difficulty in adjusting the operation properly in short tests of this kind. It is very probable that un-

der continuous operation the specific gravity separation can be more nearly duplicated. The operation of the table can be brought to the correct adjustment much more quickly because the material being treated is spread out on the table deck in full view of the operator and every stage of the separation being made is under observation; while for the adjustment of a jig the operator must depend entirely upon an examination of the products after they are discharged from the machine. This is a condition which even in continuous operation militates against the efficiency of the jig.

The fact that coal of jigging size usually contains more middling particles than the same coal crushed to finer size for table treatment also makes it more difficult to make a close specific gravity separation with the jig. This was especially true in regard to the tests on Clover Run coal and accounts in a large measure for the low efficiencies on the jig tests with this coal. The preliminary sink and float tests showed conclusively that in the larger sizes an efficient separation at 1.35 specific gravity, the solution which gave the desired quality of float coal, could not be made without a very large loss in the refuse, resulting in a prohibitively low yield of washed coal.

These tests indicate that tabling at fine size will produce a cleaner washed coal than jigging at larger sizes. This applies especially where the problem is to remove the sulfur from a coal in which it occurs as thin flakes and veinlets of pyrite. In the tests on the Clover Run coal which was of this type, the washing table, treating a feed of 0" - 3/8" size, produced a washed coal of 1.53 per cent sulfur, while the jigging test on 0" - 1" feed gave a smaller yield of washed coal analyzing 2.02 per cent

sulfur. On the West Virginia coal, which contained 70 per cent of its sulfur in the organic and fine disseminated pyritic forms, a small No. 1 coal product was separated out which analyzed 1.65 per cent sulfur and was sufficiently clean for the purpose desired, although of too fine size. This greater effectiveness of the table over the jig in reducing the sulfur content is due more to the fact that fine crushing frees the pyrite particles from the coal particles than to a more perfect separation between particles by the table; although, as the efficiency figures indicate, the latter condition is probably true in a measure.

In preparing coal for coking, where the fine size of the washed coal is no disadvantage, the table may, therefore, be used to advantage. In preparing coal for fuel the advantage of more effective cleaning is probably more than offset by the disadvantage of fine size, unless fine coal is required for some special use.